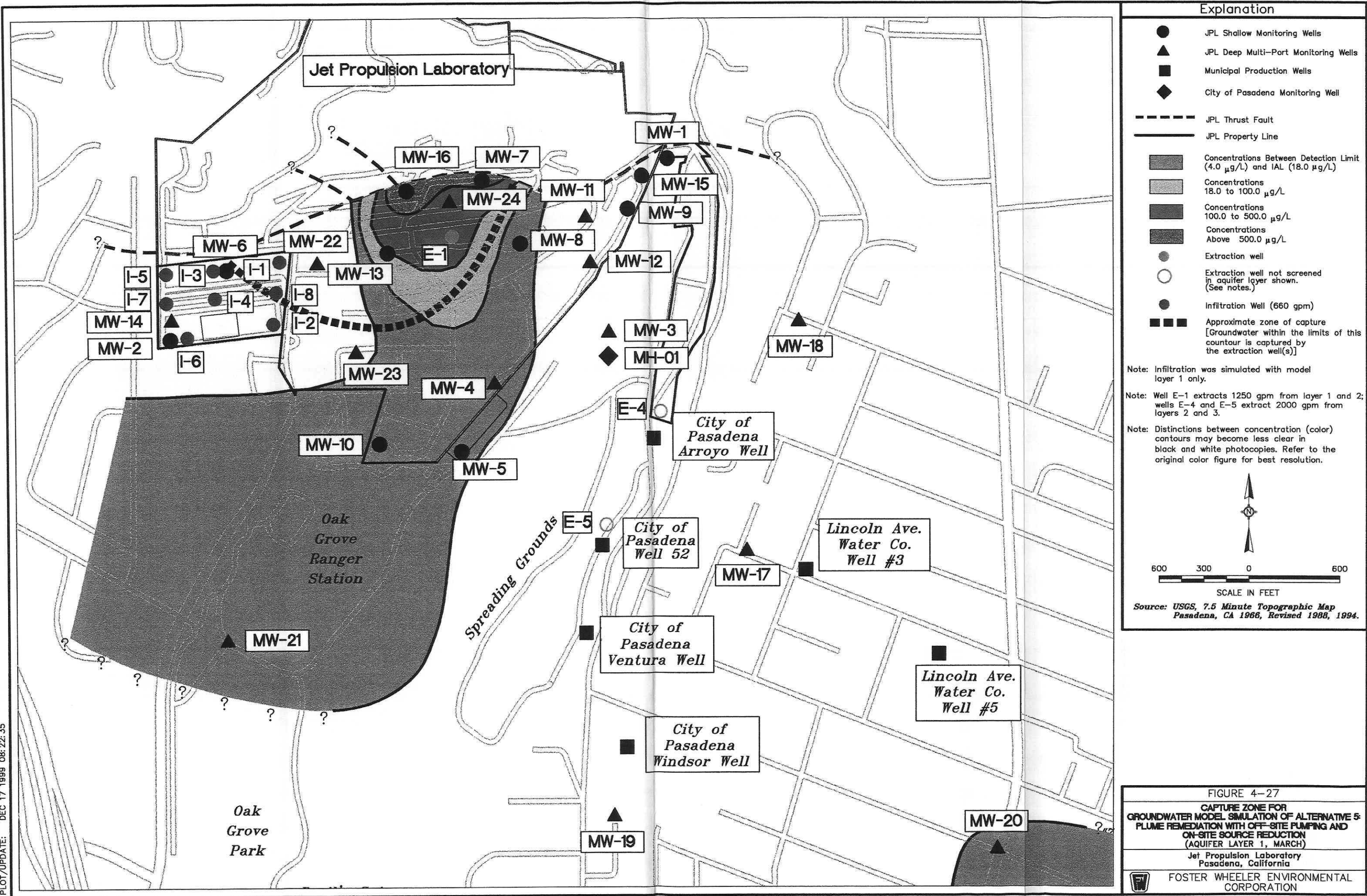
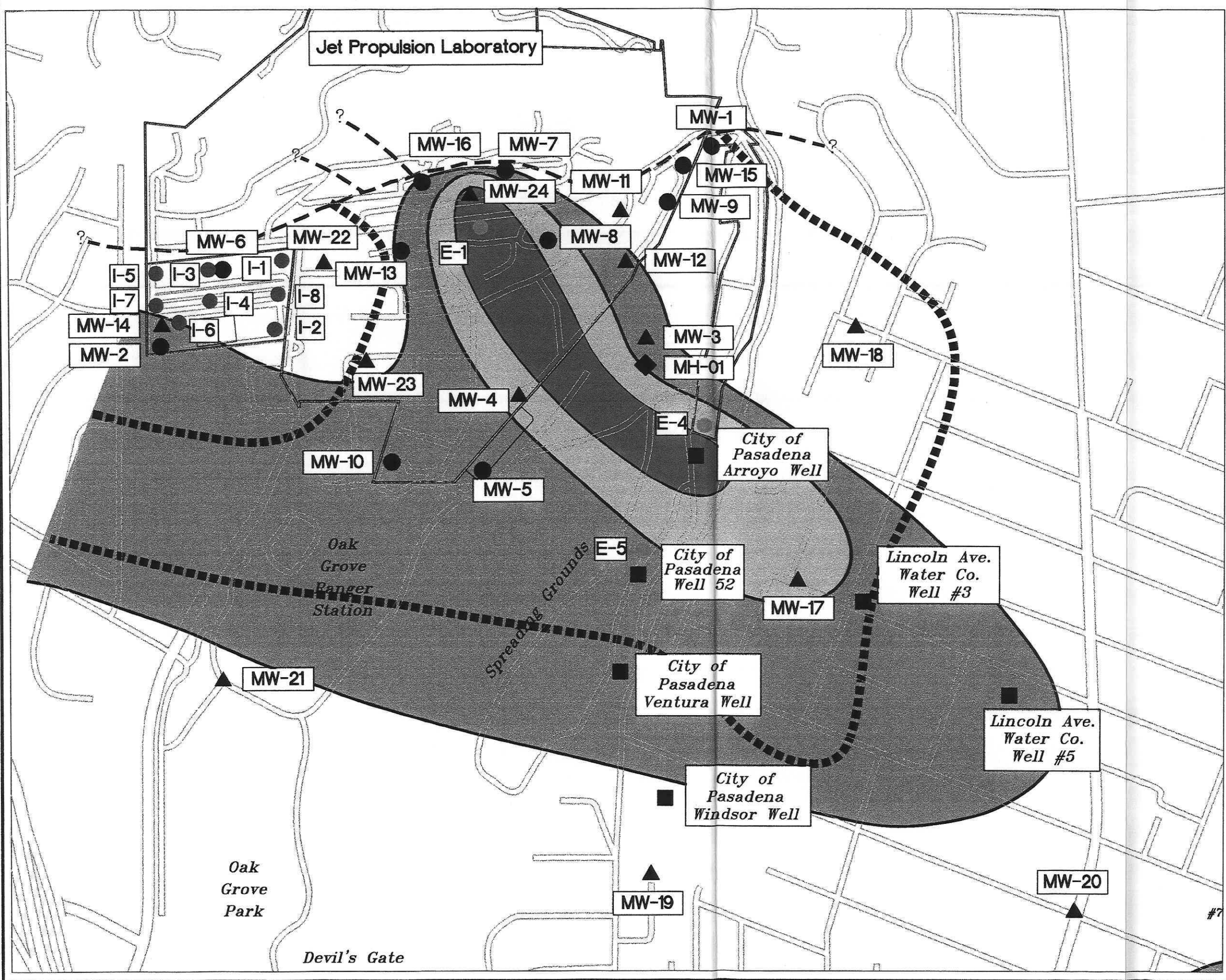


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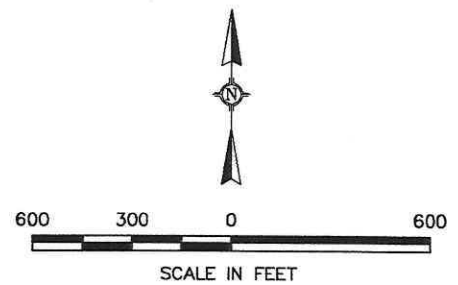
Explanation

- JPL Shallow Monitoring Wells
- ▲ JPL Deep Multi-Port Monitoring Wells
- Municipal Production Wells
- ◆ City of Pasadena Monitoring Well
- - - JPL Thrust Fault
- JPL Property Line
- Perchlorate Plume**
- Concentrations Between Detection Limit (4.0 µg/L) and IAL (18.0 µg/L)
- Concentrations 18.0 to 100.0 µg/L
- Concentrations 100.0 to 500.0 µg/L
- Extraction Well
- Infiltration Well (660 gpm)
- Approximate zone of capture [Groundwater within the limits of this contour is captured by the extraction well(s)]

Note: Infiltration was simulated with model layer 1 only.

Note: Well E-1 extracts 1250 gpm from layer 1 and 2; wells E-4 and E-5 extract 2000 gpm from layers 2 and 3.

Note: Distinctions between concentration (color) contours may become less clear in black and white photocopies. Refer to the original color figure for best resolution.



Source: USGS, 7.5 Minute Topographic Map Pasadena, CA 1966, Revised 1988, 1994.

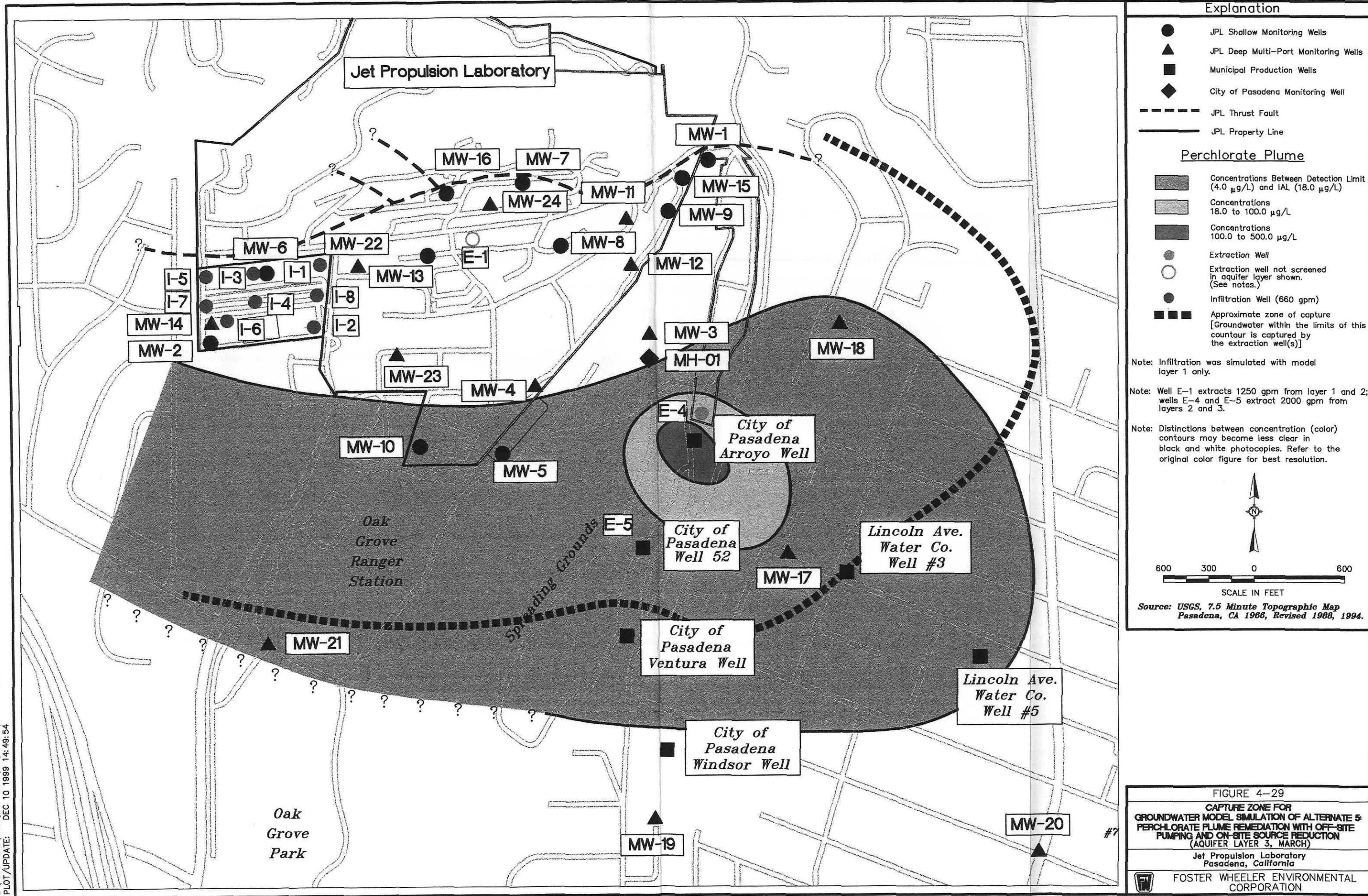
FIGURE 4-28

CAPTURE ZONE FOR GROUNDWATER MODEL SIMULATION OF ALTERNATIVE 5: PERCHLORATE PLUME REMEDIATION WITH OFF-SITE PUMPING AND ON-SITE SOURCE REDUCTION (AQUIFER LAYER 2, MARCH)

Jet Propulsion Laboratory
Pasadena, California

FOSTER WHEELER ENVIRONMENTAL CORPORATION

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5.0 DETAILED ANALYSIS OF ALTERNATIVES

The remedial alternatives developed in Section 4.0 and retained for detailed analysis are evaluated in detail in this section. The detailed evaluation of each remedial alternative includes the following:

- Refinement of the remedial alternative emphasizing the application of the technologies.
- Detailed evaluation of the remedial alternative emphasizing the criteria listed in 40 CFR Part 300.430, CERCLA Section 121(b), as amended, and the factors described in Office of Solid Waste and Emergency Response (OSWER) Directive No. 9355-01 "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (EPA, 1988a). The following nine criteria from the OSWER guidance document are used as the basis for the detailed analysis:
 1. Overall Protection of Human Health and the Environment
 2. Compliance with ARARs
 3. Long-term Effectiveness and Permanence
 4. Reduction of Toxicity, Mobility, and Volume through Treatment
 5. Short-Term Effectiveness
 6. Implementability
 7. Cost
 8. State Acceptance
 9. Community Acceptance

Factors considered for each of the evaluation criteria are summarized in Table 5-1.

Of the above listed nine evaluation criteria, only the first seven can be evaluated. Per EPA guidance, State and community acceptance will be addressed in the ROD once comments on the RI/FS report and Proposed Plan have been received (EPA, 1988a). Based on the NCP, the above nine criteria can be categorized into three groups: threshold, primary balancing, and modifying. Threshold criteria are requirements that each alternative must meet in order to be selected as a preferred alternative. These include overall protection of human health and environment and compliance with ARARs. Primary balancing criteria are the main technical criteria on which detailed evaluation of the alternatives is based. These include long-term effectiveness; reduction of toxicity, mobility and volume; short-term effectiveness; implementability; and cost. The remaining two criteria (state and community acceptance) are considered modifying criteria, and as mentioned above, will be evaluated later.

As noted in Section 4.2.2, these alternatives are primarily intended to address ClO_4^- , as VOC contamination is being addressed through current remediation activities. It is assumed for this FS that current remediation activities (i.e., treatment for VOCs and blending for ClO_4^-) of water

extracted from nearby Pasadena and Lincoln production wells will continue throughout the remedial action.

The remedial alternatives retained in Chapter 4.0 for the detailed evaluation are as follows:

- **Alternative 1: No Further Action** – Consists of the current on-going remedial activities. Groundwater is currently extracted from three City of Pasadena wells (Well #52, Windsor Well and Ventura Well) and treated for VOCs and ClO_4^- (by air stripping and blending, respectively), and from two Lincoln Avenue wells (Well #3 and Well #5) and treated for VOCs by LPGAC.
- **Alternative 2: On-Site Source Reduction** – Consists of current remedial activities plus installing an extraction well on the JPL site to pump approximately 500 gpm. The water will be treated for VOCs with air stripping, and for ClO_4^- using a system to be determined from the proposed pilot study. The treated water would be returned to the aquifer via infiltration wells.
- **Alternative 4: Plume Remediation with Off-Site Pump-and-Treat Activities Only** – Consists of current remedial activities plus additional plume remediation using two off-site extraction wells to pump approximately 4,000 gpm. The extracted water will be treated for VOCs using air stripping, and for ClO_4^- using a system to be determined by the proposed pilot study.
- **Alternative 5: Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction** – Current remedial activities plus a combination of Alternatives 2 and 4. It consists of an on-site extraction well and two off-site extraction wells (2,000 gpm each). It should be noted that the on-site well would be designed for 1,250 gpm instead of 500 gpm as in Alternative 2. This is required to create an adequate on-site capture zone as a result of reintroducing 4,000 gpm of treated water from the off-site extraction wells.

The following section provides a detailed and comparative analysis of the remedial alternatives. For each criterion, a detailed analysis for each of the alternatives is provided, followed by a comparative analysis for the alternatives. Table 5-2 presents a summary of the detailed analysis. The comparative analysis is used to rank the remedial alternatives for each criterion, the results of which are presented in Table 5-3.

5.1 ANALYSIS OF ALTERNATIVES

In this section, retained alternatives are evaluated comparatively based on criteria described above (Table 5-1). Detailed descriptions of the alternatives can be found in Chapter 4.0, (Section 2). As explained in Section 4.2.2, VOCs are primarily addressed through current on-going remedial activities. Retained alternatives are therefore screened against the EPA criteria based largely on the degree to which ClO_4^- is addressed. Since these alternatives do have a significant beneficial effect on the VOC plume, these effects are recognized, but not used to compare alternatives.

5.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion involves assessing whether each alternative provides adequate protection of human health and the environment. For this FS, an alternative is considered protective of human health with regard to ClO_4^- to the extent that it provides protection of downgradient municipal production wells, which are the only potential exposure points. As mentioned above, protection from VOCs is afforded through the current remedial activities, which were determined to meet RAOs. It should be noted that exposure to untreated JPL groundwater does not occur due to the current remedial activities. Protection of the environment is, therefore, assumed to refer to the inhibition of further downgradient contaminant migration and eliminating or minimizing the toxicity of the plumes.

The assessment of overall protection also draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. Finally, it is assumed that the VOC and ClO_4^- treatment technologies that would be used in the respective alternatives would be effective in meeting Federal and State drinking water standards.

5.1.1.1 Overall Protection of Human Health and the Environment: Detailed Analysis of Alternatives

Alternative 1 (No Further Action)

Alternative 1 consists of the current on-going remedial activities. This alternative provides protection of human health and the environment from VOCs via current VOC treatment, and from ClO_4^- via blending. The treated water is supplied to consumers and meets the regulatory requirements (drinking water standards) imposed by the EPA and the State. Therefore, this alternative is deemed to be protective of human health. However, if in the future blending were not able to reduce ClO_4^- levels to below the required limit, wells with higher ClO_4^- levels would have to be shut down. This has already occurred with the Pasadena Arroyo Well, which is currently inactive. Further increases in ClO_4^- levels in wells to the south and east of this well may potentially cause additional wells to be shut down.

The VOC plume is generally not observed to be migrating. This conclusion is based on concentrations in production and monitoring wells, which were generally observed to be stable or decreasing during the RI period (Foster Wheeler, 1999). Because of this and the current remedial activities, the No Further Action alternative would not be likely to result in adverse long-term effects with regard to VOCs. However, in the case of ClO_4^- , this alternative could lead to increases in contaminant concentrations in downgradient water supply wells. This could potentially result in the need for immediate actions that are not necessarily consistent with long-term remediation goals, such as large-scale provision of alternate water supplies. Increased cost, difficulty, and time required to meet remediation goals are also likely to occur if no further action is taken. This is due to possible continued ClO_4^- contaminant migration resulting in the need to treat larger volumes of contaminated water.

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 2 has the potential to remove significant amounts of ClO_4^- and thus, eventually protect downgradient production wells. Additional removal of VOCs would also be realized. However, the portion of the ClO_4^- plume located immediately upstream of the nearby municipal production wells is not captured. Therefore, short-term protection of these wells, beyond what is provided by the current remedial activities, is not achieved. Thus on-site source reduction by itself does not provide additional immediate protection of the nearby municipal wells, but protection is expected in the future.

Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities)

Alternative 4 would provide adequate protection from risks to human health and the environment as follows:

- It would provide continued long-term protection from VOCs through the current remedial activities,
- It would intercept the ClO_4^- plume off-site before it reached further downgradient production wells,
- It would lead to a reduction in the amount of ClO_4^- in the aquifer.

Additional protection from ClO_4^- in the short-term, and also possibly in the long-term, would continue to be provided by the current remedial activities (blending). However, because this alternative does not specify on-site extraction, off-site treatment systems may have to operate for a long time as on-site ClO_4^- migrates off site.

Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 5 is essentially a combination of Alternatives 2 and 4. The off-site component of Alternative 5 would thus provide adequate short-term and long-term protection from risks to human health and the environment. The on-site component would not provide any real short-term protection, but as in Alternative 2, protection in the long-term would be realized.

5.1.1.2 Overall Protection of Human Health and the Environment: Comparative Analysis of Alternatives

All alternatives protect human health and the environment for VOCs and ClO_4^- (based on the current remedial activities). Alternative 1 provides the least amount of over-all protection and therefore is ranked last among the four alternatives. Alternative 2 is capable of removing large amounts of ClO_4^- (and VOCs) from the source area in a short amount of time, however this does not limit migration of the off-site portion of the ClO_4^- plume, which may lead to shut-down of nearby currently operating production wells. Alternative 2 is, therefore, ranked 3rd among the four alternatives. Alternative 5 provides control and remediation of the off-site portion of the plume as well on-site source reduction. Alternative 5 is, therefore, the most protective of human

health and the environment over both the short- and long-term and is ranked 1st among the four alternatives. Alternative 4 results in control and remediation of the off-site portion of the plume, and, therefore, provides adequate protection of downgradient non-impacted production wells. However, because the majority of ClO_4^- is located on-site, Alternative 4 is less protective of the environment, since it does not directly reduce the onsite of ClO_4^- contamination. Alternative 4 is ranked 2nd among the four alternatives. It should be noted, however, that the additional protection of human health and environment in Alternative 5 may be marginal compared to Alternative 4 in the short-term.

5.1.2 Compliance with ARARs

This evaluation criterion is used to determine if each alternative would be consistent with Federal and State ARARs. The ARARs for these specific remedial alternatives are described in Section 2.0.

5.1.2.1 Compliance with ARARs: Detailed Analysis of Alternatives

Alternative 1 (No Further Action)

Alternative 1 does not meet all ARARs because it allows for the continued migration of ClO_4^- , at levels potentially exceeding the IAL, toward non-impacted production wells. Specifically, the No Further Action alternative would conflict with SWRCB Resolution 92-49, which requires that contaminated groundwater be cleaned up to background water quality levels, or to the best quality of water that is reasonable if background can not be attained. The No Further Action Alternative would also conflict with SWRCB Resolution 68-16, which requires that existing water quality be maintained. Existing water quality downgradient of JPL would be impacted by continuing migration of ClO_4^- .

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities), Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities), and Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

Alternatives 2, 4, and 5 all involve capture of ClO_4^- impacted groundwater followed by treatment and re-introduction into the aquifer. Therefore, the ARARs for these three proposed alternatives are similar. Extraction and treatment of groundwater impacted with ClO_4^- meets the Federal and State ARARs identified in Section 2.0. However, re-introduction of treated groundwater to the Monk Hill Sub-basin, either directly through injection wells, or more gradually through infiltration galleries, requires a more detailed evaluation in determining whether the action satisfies ARARs. The key ARARs affecting groundwater re-introduction are described and evaluated below.

SWRCB Resolution 68-16

SWRCB Resolution 68-16, which requires that "existing water quality be maintained unless it is demonstrated that a change will benefit the people of California, will not unreasonably affect present or potential uses, and will not result in water quality less than prescribed by other State policies. Any activity that may increase the volume or concentration of a waste discharged to surface or groundwater is required to use the best practicable treatment or control." To satisfy this ARAR, the treatment of water proposed for re-introduction would need to meet the aforementioned Resolution 68-16 conditions.

LARQWCB Basin Plan

The LARQWCB Basin Plan, as prepared under the authority of the Porter-Cologne Water Quality Act, requires the LARWQCB to administer Waste Discharge Requirements (WDRs) for discharges to surface or groundwater. As a CERCLA action, the substantive requirements of the WDRs from the LARWQCB would need to be met even if the permit itself were not required. The requirements would consider the beneficial uses and water quality objectives for the affected water body (e.g., Monk Hill Sub-basin) as well as the mixing and dilutionary effects.

Toxic Injection Well Control Act

The Toxic Injection Well Control Act codified in Section 25159.24 of the California Health and Safety Code states that any injection well used to inject contaminated groundwater that has been treated and is being re-injected into the same formation from which it was withdrawn for the purpose of improving the quality of the groundwater in the formation is exempt from the toxic injection well control act standards if the method is part of a remedial program initiated in response to an order or action required by a Federal or State agency. Therefore, the re-introduction of treated groundwater via re-injection would be exempt from the requirements of the Toxic Injection Well Control Act because the remedial program would be implemented under a ROD approved by the EPA.

Porter-Cologne Water Quality Act

Section 13540 of the Porter-Cologne Water Quality Act states that "no person shall construct, maintain or use any waste well extending to or into a subterranean water bearing stratum that is used or intended to be used as, or is suitable for, a source of water supply for domestic purposes. Notwithstanding the foregoing, when a regional board finds that the water quality considerations do not preclude controlled recharge of such stratum by direct injection, and when the State Department of Health Services, following a public hearing, finds the proposed recharge will not impair the quality of water in the receiving aquifer as a source of water supply for domestic purposes, recycled water may be injected by a well into such stratum. The State Department of Health Services may make and enforce such regulations pertaining thereto, as it deems proper." Since the proposed re-introduction of treated groundwater would not impair the quality of water in the receiving aquifer as a source of water supply for domestic purposes, Alternatives 2, 4, and 5 meet this ARAR. However, the CADHS would have to make this finding in order to completely meet this ARAR.

5.1.2.2 Compliance with ARARs: Comparative Analysis of Alternatives

Alternative 1 is assigned a low ranking to reflect the conclusion that it does not meet all ARARs. Alternatives 2, 4 and 5 are assigned a high ranking because these alternatives are likely to meet ARARs. There are no significant differences between Alternatives 2, 4 and 5 in consideration of and compliance with ARARs.

5.1.3 Long-Term Effectiveness and Permanence

The long-term effectiveness evaluation criterion is used to assess each remedial alternative in terms of the risk remaining at the site after the remedial action objectives are met. This evaluation is intended to focus primarily on the extent and effectiveness of controls that may be required to manage risk posed by treatment residuals and/or untreated groundwater.

Treatment residuals may include spent carbon from VOC removal techniques, and concentrated brine and/or biologically treated RO rejectate from ClO_4^- treatment, depending on which techniques are used. In this FS, the performance of the alternatives with respect to the long-term effectiveness criterion is evaluated by estimating the extent to which each alternative removes contaminant mass and prevents the migration of contamination into less contaminated areas of the aquifer. Treatment residuals are not considered, since ClO_4^- treatment techniques have not been decided upon, and disposal of spent carbon from VOC treatment poses no risk.

5.1.3.1 Long-Term Effectiveness and Permanence: Detailed Analysis of Alternatives

As previously mentioned, all of the alternatives provide adequate long-term protection from migration of VOCs (and to a lesser extent from ClO_4^- migration) through the current remedial activities (see Section 4.2.2). Alternatives were therefore evaluated against this criterion by the extent to which they remove contaminant mass and prevent the migration of contamination into less contaminated areas of the aquifer, specifically towards non-impacted downgradient production wells. The types of technologies and process options are essentially similar for all alternatives, and until the proposed pilot study (Section 4.2.2) is completed, all are considered equally reliable. Therefore, no distinction is made between the different alternatives in terms of long-term reliability of treatment technologies.

Alternative 1 (No Further Action)

Alternative 1 currently reduces the mass of VOCs and ClO_4^- in the aquifer, but at a comparatively slow rate. If ClO_4^- levels were to rise in the future, production wells may have to be shut down to meet treatment requirements, thereby decreasing the effectiveness of this alternative. Therefore this alternative is not considered effective in the long-term.

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 2 will remove a significant portion of ClO_4^- from the JPL source area. VOCs would also be removed, but a smaller percentage of the total VOC contamination is contained within the source area, and thus this action would be relatively less effective for VOCs. Under Alternative 2, there would be no additional off-site remediation, and, therefore, no immediate

additional ClO_4^- removal from the off-site portion of the plume, which may lead to further increases (short-term) in ClO_4^- levels in downgradient production wells. In summary, Alternative 2 does not provide an additional mechanism for direct removal of ClO_4^- from the off-site portion of the plume, but will most likely result in reduction in levels of ClO_4^- at the production wells in the future. Alternative 2 is, therefore, considered effective in the long-term when operated in conjunction with current remedial activities.

Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities)

Alternative 4 would lead to interception the ClO_4^- plume, prior to its reaching downgradient non-impacted production wells, as suggested by the modeling output for this alternative (see Section 4.2.3.4, and Appendix H). Under this alternative, treatment systems for ClO_4^- would be operated until (1) ClO_4^- levels in the extracted water are consistently below treatment goals, and (2) ClO_4^- concentrations in the aquifer, as determined by groundwater monitoring, are reduced to acceptable levels. Although this would provide adequate protection, the long-term effectiveness of this alternative is questionable because substantial time is likely to be required for the ClO_4^- , the majority of which is still located on-site, to migrate to the vicinity of the off-site extraction/treatment wells. For this reason, Alternative 4 is viewed as being somewhat less effective in the long-term.

Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 5 would lead to removal of a major percentage of ClO_4^- from the JPL source area as well as interception the off-site ClO_4^- plume. Together, the on-site and off-site components of this provide for very effective long-term (as well as short-term) protectiveness of human health and the environment.

5.1.3.2 Long-Term Effectiveness and Permanence: Comparative Analysis of Alternatives

Alternative 1 is the least proficient in terms of long-term effectiveness because the migration of portions of the off-site ClO_4^- plume is not inhibited, which may lead to shut-down of other nearby production wells in the future if ClO_4^- levels rise. Alternative 1 is, therefore, is ranked last (4th) among the four alternatives. Alternative 2 is capable of removing large amounts of ClO_4^- (and VOCs) from the JPL source area. This makes it very favorable in terms of long-term effectiveness because of the potential for removing a large percentage of the ClO_4^- relatively quickly, as well as reducing the long-term load on currently operating VOC systems. Although Alternative 2 does not limit migration of portions of the off-site ClO_4^- plume, this is considered a short-term issue, and Alternative 2 is rated 2nd among the alternatives in terms of long-term efficiency. Alternative 4 results in control and remediation of the off-site portion of the plume, and therefore provides adequate long-term protection of non-impacted production wells via ClO_4^- removal and control of its migration. However, because the majority of ClO_4^- from the JPL source area is located on-site, an exceedingly long time may be required to treat the plume via

off-site wells only, and thus Alternative 4 may be relatively inefficient over the long-term. Alternative 4 is therefore considered less effective than Alternative 2 with regards to long-term efficiency and is ranked 3rd among the four alternatives. Alternative 5 provides control and remediation of the off-site portion of the plume plus on-site source reduction. While its short-term effectiveness is similar to that of Alternative 4, a significant increase in long-term effectiveness would be realized due to implementation of on-site source reduction activities. This allows for maximum contaminant removal and inhibition of migration, and is therefore the most effective (ranked 1st) among the alternative in terms of long-term efficiency.

5.1.4 Reduction of Toxicity, Mobility, and Volume through Treatment

This criterion is intended to assess the propensity of each alternative to significantly reduce toxicity, mobility, and volume of the contaminants as a principal element of the action. This may be through destruction of toxic contaminants, reduction of total mass of toxic contaminants, irreversible reduction in contaminant mobility, and/or reduction of total volume of contaminated media. Since the technologies for treatment of extracted groundwater are the same for all alternatives at this time (VOCs sorbed on carbon, ClO_4^- destroyed), this criterion is assessed by estimating the reduction in contaminant volume (mass) and mobility for each alternative.

5.1.4.1 Reduction of Toxicity, Mobility, and Volume: Detailed Analysis of Alternatives

Alternative 1 (No Further Action)

Reduction of mobility and volume of VOCs and ClO_4^- are currently being achieved for Alternative 1 through current remedial activities. However, if ClO_4^- levels were to rise or if the State IAL were to be significantly lowered causing additional production wells to be shut down, reduction of both VOCs and ClO_4^- would be adversely affected.

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 2 is designed to remove a major percentage of ClO_4^- , as well as VOCs present in the extracted water, while off-site VOCs and ClO_4^- are addressed through the current remedial activities. This alternative leads to a significant reduction in ClO_4^- volume, as well as potential inhibition of migration of on-site ClO_4^- into the off-site portions of the aquifer. Alternative 2 does not, however, have the potential to remove significant amounts of off-site ClO_4^- , other than through blending at the nearby municipal wells. If ClO_4^- levels rise over time, blending may no longer be feasible.

Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities)

Alternative 4 would lead to off-site interception of the ClO_4^- plume, and therefore reduce the possibility for further downgradient migration (i.e. mobility) toward non-impacted production wells. The mobility of the VOC plume would also be reduced, as would the contaminant volume, since the major portion of the VOCs is off-site. Reduction of volume of the ClO_4^- would not be

as significant as for VOCs, since the majority of ClO_4^- from the JPL source area is located on-site.

Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 5 would lead to removal a major percentage of ClO_4^- (and VOCs) from the source area as well as interception the off-site ClO_4^- plume. This would accomplish major reductions in volume as well as mobility of ClO_4^- , as well as of VOCs.

5.1.4.2 Reduction of Toxicity, Mobility, and Volume: Comparative Analysis of Alternatives

Alternative 1 is the least efficient in terms of reduction of toxicity, mobility, and volume because migration of ClO_4^- toward currently operating production wells is not reduced, and no direct ClO_4^- treatment techniques are implemented. Alternative 1 is therefore is ranked last (4th) among the four alternatives. Alternative 2 is capable of removing large amounts of ClO_4^- from the source area. However, Alternative 2 does not reduce the migration of portions of the off-site ClO_4^- plume toward currently operating production wells. Alternative 2 is thus rated 3rd among the alternatives in terms of reduction of toxicity, mobility, and volume. Alternative 4 results in reduction in contaminant volume, as well as in mobility of the off-site portion of the plume, therefore protecting non-impacted downgradient production wells from ClO_4^- . However, because the majority of ClO_4^- from the JPL source area is located on-site, an extended period of time may be required to reduce the volume (mass) of ClO_4^- using off-site extraction wells only. Nevertheless, because it provides for reduction in contaminant volume (mass) as well as reducing further off-site contaminant migration, Alternative 4 is considered more effective than Alternative 2 in terms of reducing mobility, and is ranked 2nd among the four alternatives. It is assumed here that reduction in mobility (potential for impacting production wells) takes precedent over reduction in volume. Alternative 5 provides for reduction of mobility of the off-site and on-site portions of the plume. This allows for maximum reduction of contaminant volume (mass) and in reduction of contaminant migration, and is therefore the most effective (ranked 1st) among the alternatives.

5.1.5 Short-Term Effectiveness

The short-term effectiveness criterion is used to evaluate the effects of each remedial alternative on human health and the environment during the construction and implementation phase until remedial action objectives are met. The following factors are addressed for each alternative:

- Protection of workers and the community during construction and implementation phases. This factor qualitatively examines risk that results from implementation of the proposed remedial action and the effectiveness and reliability of protective measures.

- Environmental impacts. This factor addresses the potential adverse environmental impacts that may result from the construction and implementation of an alternative. This factor also evaluates the reliability of the available mitigation measures to prevent or reduce potential impacts.

5.1.5.1 Short-Term Effectiveness: Detailed Analysis of Alternatives

None of the remedial action alternatives pose significant risks to the community during construction and implementation. Nor do any of the alternatives pose such risks to workers beyond general construction hazards associated with large construction projects. No unmitigable negative environmental impacts are anticipated in the areas in which facilities would be constructed. The same technologies are used for all alternatives, resulting in similar short-term reliabilities for all alternatives.

Alternative 1 (No Further Action)

Alternative 1 provides adequate short-term effectiveness, since it does not involve any new construction.

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 2 provides adequate protection of the workers and community during implementation. There is no risk to the community, since all of the components are on the JPL site. Environmental impacts due to implementation of this alternative are minimal. Installation of extraction and infiltration wells will have some mitigable impacts, as will the trenches that will be required for conveyance piping.

Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities)

Alternative 4 provides adequate protection of workers and the community during implementation. Since there is construction offsite, there may be some risk to the community, which will be mitigated by taking appropriate measures during construction. Environmental impacts are minimal. Installation of extraction and infiltration wells will have some mitigable impacts, as will the trenches that will be required for conveyance piping. Implementation of the off-site portion also requires trenching across the Arroyo. Impacts to the environment will be only during construction, and will be appropriately mitigated.

Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

Alternative 5 provides adequate protection of workers and the community during implementation. Since there is construction offsite, there may be some risk to the community, which will be mitigated by taking appropriate measures during construction. Environmental impacts are minimal. Installation of extraction and infiltration wells will have some mitigable impacts, as will the trenches that will be required for conveyance piping. Implementation of the off-site portion also requires trenching across the Arroyo. Impacts to the environment will be only during construction, and will be appropriately mitigated.

5.1.5.2 Short-Term Effectiveness: Comparative Analysis of Alternatives

All alternatives provide adequate short-term protection of human health and the environment from VOCs and ClO_4^- based on current remedial activities. Since Alternative 1 does not require any construction, it provides the greatest degree of short-term effectiveness, hence, it is ranked 1st. Alternative 2 does not require any off-site construction, hence, it is ranked 2nd. Both Alternatives 4 and 5 require essentially similar off-site construction, hence, they are both ranked 3rd.

5.1.6 Implementability

The implementability criterion addresses the technical and administrative feasibility associated with implementing an alternative, as well as the availability of various services and materials required during its implementation. This criterion involves consideration of the following factors:

Technical Feasibility

- Construction and operation: assesses any technical difficulties and unknowns associated with the various technologies.
- Reliability of technology: focuses on the likelihood that technical problems associated with implementation will lead to schedule delays.
- Ease of undertaking additional remedial action: involves consideration of what, if any, future remedial actions may need to be undertaken and how the remedial action would interfere with, or facilitate, the implementation of future actions.
- Monitoring considerations: assesses the ability to monitor the effectiveness of the remedial action, including an evaluation of risks of exposure should monitoring be insufficient to detect a system failure.

Administrative Feasibility

- Activities expected to be needed for coordination with other agencies, including agencies other than EPA, to obtain permits for the various aspects of implementation and operation.

Availability of Services and Materials

- Availability of necessary equipment, specialists and provisions to assure any necessary resources.
- Availability of services and materials, plus the potential for obtaining competitive bids.
- Availability of prospective technologies.

5.1.6.1 Implementability: Detailed Analysis of Alternatives

The above-mentioned categories are discussed below with reference to Alternatives 1, 2, 4 and 5.

Technical Feasibility: Construction and Operation – The extraction, VOC treatment, water/waste conveyance and groundwater monitoring technologies included in Alternatives 2, 4 and 5 are widely used. No significant difficulties are expected in construction and operation of these technologies. As explained in Appendix B, treatment technologies for ClO_4^- are not well established for long-term implementation (particularly with regard to destruction of ClO_4^-), although at present, they appear to be feasible. Implementability issues related to ClO_4^- treatment are expected to become more clear following the proposed pilot study (Section 4.2.2). The JPL site does pose some unique problems for construction, due to the proliferation of buried utilities, many of which are critical to JPL's operations. Therefore, alternatives that involve construction on-site (i.e. Alternatives 2 and 5) will require special considerations.

Technical Feasibility: Reliability of Technology – The extraction, VOC treatment, conveyance and monitoring technologies in Alternatives 2, 4 and 5 are generally known to be proven and reliable. However, ClO_4^- treatment has not been proven for long-term implementability, and will therefore be tested during the proposed pilot study.

Technical Feasibility: Ease of Undertaking Additional Remedial Actions – None of the alternatives would interfere with the implementation of potential future response actions in the JPL area.

Technical Feasibility: Monitoring Considerations – A comprehensive monitoring program is included within each alternative to monitor the effectiveness and assess the progress of the remedial activities. This includes the current JPL Long-Term Quarterly Monitoring Program (Foster Wheeler, 1996a) and DHS-required monitoring of all nearby municipal production wells, to which would be added a strict program to monitor effluent from treatment systems. This program will also be expected to provide information as to potential modifications in extraction rates, or to treatment methods to ensure attainment of remedial objectives.

Administrative Feasibility – Implementation of Alternatives 4 and 5 would require acquisition of property and/or easements for the construction of extraction wells, and conveyance facilities off-site. Acquisition of offsets for air emissions may also be required for the VOC treatment portions of the alternatives.

Implementation of Alternatives 2, 4 and 5 would also require resolution of the following administrative issues associated with groundwater extraction and discharge of treated water at JPL:

- Agreements would need to be made with the Raymond Basin Watermaster and/or the Raymond Basin Management Board, and, potentially, affected water purveyors to account for groundwater not returned or appropriately used in the basin.

- If water extracted and treated (excludes current remedial activities) were to be provided for domestic consumption or irrigation purposes, agreements would need to be reached with recipients, specifying the amount of water that would be accepted, the treated water delivery location, responsibility for any necessary capital improvements to distribution systems, and to determine operational, liability, financial, and other arrangements.
- Approval would have to be obtained from the RWQCB for re-introduction of treated water via re-injection to the aquifer. Although no permit has to be obtained for CERCLA remedial actions conducted on-site, the substantive requirements of the Porter-Cologne Water Quality Act and the implementing regulations must be met. Formal approval would also be required from the RWQCB for re-introduction via re-infiltration wells.
- Approval would have to be obtained from the local Sanitation District for discharge of treatment wastes to the sewer. Although no permit has to be obtained for CERCLA remedial actions conducted on-site, the substantive requirements of the Sanitation District must be met.

Availability of Services and Materials – Implementation of Alternatives 2, 4 and 5 would require construction of various equipment. Required services and materials are believed to be available, including qualified contractors for construction and operation of the technologies under consideration.

5.1.6.2 Implementability: Comparative Analysis of Alternatives

Alternative 1 has already been successfully implemented, and since no additional implementation is thus required, Alternative 1 is ranked 1st among the alternatives in this category. Alternatives 2, 4 and 5 are comprised of essentially the same components and are therefore similar with regards to implementation. However, due to the differences in sizing of the treatment and conveyance facilities (500 gpm, 4,000 gpm, and 5,250 gpm for Alternatives 2, 4 and 5, respectively), it is expected that technical feasibility would decrease with increasing size of the facilities. Additional differences, however, may also influence implementability, the most important of these being that Alternatives 2 and 5 will require more significant on-site construction, than that required by Alternative 4. Alternatives 2, 4 and 5 are also similar with regard to administrative issues associated with groundwater extraction, treatment and disposal, with some marginal differences due to size. Because Alternative 4 requires larger equipment than is required for Alternative 2, but Alternative 2 requires more extensive on-site construction, Alternatives 2 and 4 are considered to be essentially equal in terms of implementability and are both ranked 2nd. Alternative 5 has the largest size, and involves on-site and off-site construction, and is therefore ranked 4th.

5.1.7 Cost

This criterion addresses the total estimated cost of each alternative. This includes short- and long-term costs, capital, and operation and maintenance (O&M) costs. The following cost elements are considered for Alternatives 2, 4, and 5:

- **Capital Cost.** Direct capital cost includes the cost of construction, labor, equipment, land, site development and service cost. Indirect capital cost includes engineering fees, license and permit cost, startup and shakedown cost and contingencies.
- **O&M Cost.** Annual O&M cost includes operating labor cost, maintenance materials and labor, pumping and treatment energy costs, monitoring costs, and all other post-construction costs necessary to ensure continuous effective operation of the alternative.
- **Total Present Worth.** The total present worth of each alternative is calculated at an interest rate of 5% and a time period of 30 years. Total present worth for each alternative includes capital cost plus the present worth of the annual O&M costs.

Remediation costs are not considered for Alternative 1, i.e., for current remedial alternatives, since these are common to all alternatives, and therefore would not be of use in comparing alternatives based on costs.

The cost estimates are considered order-of-magnitude level estimates (i.e., the cost estimates have an expected accuracy of +50 to -30 percent per EPA guidance) and are provided in Appendix I. The cost estimates for each alternative are divided into three main groups, each with various cost elements, as follows:

1. **Collection** – Elements include extraction wells, conveyance piping from the extraction wells to the treatment area, etc. Costs for capital and O&M are considered for each element.
2. **Treatment** – Elements include air stripping and vapor phase GAC for VOCs, reverse osmosis/biotreatment, and ion exchange/catalytic destruction for ClO_4^- . Costs for capital and O&M are considered for VOCs, a combination of reverse osmosis and biotreatment and a combination of ion exchange and catalytic destruction for ClO_4^- .
3. **Disposition of Treated Water and Waste Streams** – Elements include conveyance piping to the sewer, sewer connection fees, and annual sewer discharge fees.

As discussed in Section 4.0, the selected ClO_4^- treatment train will potentially be comprised of RO and IE in a configuration which will depend upon results the proposed pilot study. It is possible that the final treatment system will include fewer process options than those proposed for the pilot study. The treatment costs provided here are, therefore, conservative, and illustrate potential worst-case scenarios.

The present worth has been estimated based on a discount rate of 5 percent and an operating period of 30 years. The assumption of a 30-year operating period is based on EPA guidance and does not reflect any specific finding regarding the duration of the remedy.

5.1.7.1 Cost: Detailed Analysis of Alternatives

Table 5-4 summarizes the estimated costs for Alternatives 2, 4, and 5. As described in Appendix I, numerous assumptions have been made in estimating these costs. Furthermore, the cost estimates are intended to allow comparison of the alternatives, rather than provide an actual estimate of implementation of a particular alternative.

Alternative 1 (No Further Action)

Since the current remedial alternatives are ongoing as part of Alternative 1, no additional costs are assumed to be incurred. Groundwater monitoring costs will be incurred and are estimated to have a present worth of \$11,598,889, based on \$750,000 annual costs, 30 years duration, and a 5% discount rate. Five-year revisions to the monitoring program would be conducted in accordance with EPA requirements. Costs of such reviews are expected to be approximately \$25,000, and have been included.

Alternative 2 (On-Site Source Reduction, in conjunction with current remedial activities)

As shown in Table 5-4, the estimated capital cost of Alternative 2 is \$7,670,299, and the estimated present worth of O&M and groundwater monitoring is \$24,429,604. The total estimated cost is \$32,099,903.

Alternative 4 (Plume Remediation with Off-Site Pump-and-Treat Activities Only, in conjunction with current remedial activities)

As shown in Table 5-4, the estimated capital cost of Alternative 4 is \$29,016,663, and the estimated present worth of O&M and groundwater monitoring is \$83,433,457. The total estimated cost is \$112,450,120.

Alternative 5 (Plume Remediation with Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction, in conjunction with current remedial activities)

As shown in Table 5-4, the estimated capital cost of Alternative 5 is \$38,220,419, and the estimated present worth of O&M and groundwater monitoring is \$106,372,874. The total estimated cost is \$144,593,293.

5.1.7.2 Cost: Comparative Analysis of Alternatives

As indicated above, Alternative 1 costs the least, while Alternative 5 costs the most. Therefore, based on cost, Alternative 1 is ranked 1st, Alternative 2 is ranked 2nd, Alternative 4 is ranked 3rd, and Alternative 5 is ranked 4th.

5.1.8 State Acceptance

This criterion evaluates the technical and administrative issues and concerns the state may have regarding each alternative. This criterion will be addressed in the ROD and responsiveness summary.

5.1.9 Community Acceptance

This criterion evaluates the issues and concerns the public may have regarding each alternative. As with state acceptance, this criterion will be evaluated in the ROD and responsiveness summary, once public comments on this FS and the proposed plan have been received.

TABLES

TABLE 5-1

**FACTORS FOR DETAILED EVALUATION OF ALTERNATIVES
JET PROPULSION LABORATORY**

Overall Protection	How alternative provides human health and environmental protection.
Compliance with ARARs	Compliance with chemical-specific ARARs. Compliance with location-specific ARARs. Compliance with action-specific ARARs. Compliance with other criteria, advisories, and guidance.
Long-Term Effectiveness and Permanence	Reduction of existing risks. Magnitude of future risks. Long-term reliability. Prevention of future exposure to residuals.
Reduction of Toxicity, Mobility, and Volume Through Treatment	Amount of hazardous materials destroyed or treated. Degree of expected reductions in toxicity, mobility, and volume. Degree to which treatment is irreversible. Type and quantities of residuals remaining after treatment.
Short-Term Effectiveness	Time until protection is achieved. Short-term reliability of technology. Protection of community during remedial actions.
Implementability	Ability to operate and construct the technology. Ability to phase into operable units. Ease of undertaking additional remedial actions, if necessary. Ability to monitor effectiveness of remedy. Ability to obtain approvals from other agencies. Coordination with other agencies. Availability of treatment, storage, and disposal services and capacity. Availability of necessary equipment and specialists.
Cost	Construction costs. Operating costs for implementing remedial action. Other capital and short-term costs until remedial action is complete. Costs of operation and maintenance for as long as necessary. Costs of 5-year reviews (if required).
State Acceptance ⁽¹⁾	Features of the alternative the state supports. Features of the alternative about which the state has reservations. Features of the alternative the state strongly opposes.
Community Acceptance ⁽¹⁾	Features of the alternative the community supports. Features of the alternative about which the community has reservations. Features of the alternative the community strongly opposes.

Notes:

(1): Not evaluated in Feasibility Study because of limited available information. State and community acceptance will be fully addressed in the Record of Decision (ROD).

TABLE 5-2

**SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES
JET PROPULSION LABORATORY**

Alternative ⁽¹⁾	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost
1. No Further Action	<ul style="list-style-type: none"> Provides protection via current VOC treatment, and by blending for ClO₄⁻ Could decrease if ClO₄⁻ levels were to rise 	<ul style="list-style-type: none"> Does not comply with all ARARs 	<ul style="list-style-type: none"> Currently reduces mass of VOCs and ClO₄⁻ Will decrease with potential increasing ClO₄⁻ levels in off-site wells 	<ul style="list-style-type: none"> Currently reduced via ongoing pumping and treatment Could increase if ClO₄⁻ levels rise, which would cause wells to be shut down. This in turn would increase mobility 	<ul style="list-style-type: none"> Effective in short-term, since it does not require any construction 	<ul style="list-style-type: none"> This has already been implemented 	<ul style="list-style-type: none"> No additional cost, other than groundwater monitoring Capital Cost \$0 Present Worth \$11,598,889 Total \$11,598,889
2. On-Site Source Reduction	<ul style="list-style-type: none"> No immediate protection for off-site ClO₄⁻ (beyond current remedial activities) Protection of off-site wells in the future, for ClO₄⁻ 	<ul style="list-style-type: none"> Complies with ARARs 	<ul style="list-style-type: none"> Will remove significant portion of ClO₄⁻ Does not provide for removal of ClO₄⁻ that is already off-site 	<ul style="list-style-type: none"> Reduces volume of ClO₄⁻, and to a great extent mobility No direct additional reduction of off-site VOCs and ClO₄⁻ 	<ul style="list-style-type: none"> No impact to community Workers will be protected by appropriate measures during construction 	<ul style="list-style-type: none"> The technologies (air stripping, liquid and vapor phase GAC, reverse osmosis, and ion exchange) are widely used These technologies are reliable There is uncertainty regarding treatment of reverse osmosis rejectate and ion exchange brine – these will be addressed by the proposed pilot study 	<ul style="list-style-type: none"> Requires capital, O&M, and groundwater monitoring Capital Cost \$7,670,299 Present Worth \$24,429,604 Total \$32,099,903

TABLE 5-2

**SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES
JET PROPULSION LABORATORY**

Alternative ⁽¹⁾	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost
						<ul style="list-style-type: none"> On-site construction may present problems due to proliferation of buried utilities 	
4. Off-Site Pump-and-Treat Activities Only	<ul style="list-style-type: none"> Provides immediate and continued long-term protection Would intercept off-site ClO_4^- plume 	<ul style="list-style-type: none"> Complies with ARARs 	<ul style="list-style-type: none"> Provides interception of off-site ClO_4^- plume May take substantial time to address ClO_4^-, which is mostly on site 	<ul style="list-style-type: none"> Reduces volume of off-site VOCs and ClO_4^- 	<ul style="list-style-type: none"> Workers and community will be protected by appropriate measures during construction 	<ul style="list-style-type: none"> The technologies (air stripping, liquid and vapor phase GAC, reverse osmosis, and ion exchange) are widely used These technologies are reliable There is uncertainty regarding treatment of reverse osmosis rejectate and ion exchange brine – these will be addressed by the proposed pilot study 	<ul style="list-style-type: none"> Requires capital, O&M, and Groundwater Monitoring Capital Cost \$29,016,663 Present Worth \$83,433,457 Total \$112,450,120
5. Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction	<ul style="list-style-type: none"> Provides immediate and continued long-term protection Would intercept off-site ClO_4^- plume 	<ul style="list-style-type: none"> Complies with ARARs 	<ul style="list-style-type: none"> Provides interception of off-site ClO_4^- plume Will remove significant portion of ClO_4^- 	<ul style="list-style-type: none"> Reduces volume of off-site VOCs and ClO_4^- 	<ul style="list-style-type: none"> Workers and community will be protected by appropriate measures during construction 	<ul style="list-style-type: none"> The technologies (air stripping, liquid and vapor phase GAC, reverse osmosis, and ion exchange) are widely used These technologies are reliable 	<ul style="list-style-type: none"> Requires capital, O&M, and Groundwater Monitoring Capital Cost \$38,220,419 Present Worth \$106,372,874

TABLE 5-2

**SUMMARY OF DETAILED ANALYSIS OF ALTERNATIVES
JET PROPULSION LABORATORY**

Alternative ⁽¹⁾	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Implementability	Cost
						<ul style="list-style-type: none"> There is uncertainty regarding treatment of reverse osmosis rejectate and ion exchange brine – these will be addressed by the proposed pilot study On-site construction will present problems due to proliferation of buried utilities 	<ul style="list-style-type: none"> Total \$144,593,293

Notes:

(1): All alternatives also include current remedial activities.

TABLE 5-3
RANKING⁽¹⁾ OF ALTERNATIVES
JET PROPULSION LABORATORY

Alternative ⁽²⁾	Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, and Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Community Acceptance
1. No Further Action	4	4	4	4	1	1	1	TBD	TBD
2. On-Site Source Reduction	3	1	2	3	2	2	2	TBD	TBD
4. Off-Site Pump-and-Treat Activities Only	2	1	3	2	3	2	3	TBD	TBD
5. Off-Site Pump-and-Treat Activities Plus On-Site Source Reduction	1	1	1	1	3	4	4	TBD	TBD

Notes:

(1): Alternatives are comparatively ranked within each of the EPA criteria from 1 (most favorable) to 4 (least favorable).

(2): All alternatives also include current remedial activities.

TBD: To be determined.

TABLE 5-4

**SUMMARY OF COST ESTIMATES
JET PROPULSION LABORATORY**

Alternative	Capital	Present Worth – O&M and Groundwater Monitoring	Total
1	--	\$11,598,889	\$11,598,889
2	\$7,670,299	\$24,429,604	\$32,099,903
4	\$29,016,663	\$83,433,457	\$112,450,120
5	\$38,220,419	\$106,372,874	\$144,593,293

Notes:

See Appendix I for cost estimates.

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APPENDIX A

MONITORED NATURAL ATTENUATION OF VOCs

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APPENDIX A

MONITORED NATURAL ATTENUATION OF VOCs

1.0 INTRODUCTION

The transport and behavior of various contaminants in soil/water systems is influenced by what have been termed "natural attenuation" (NA) mechanisms. These can include physical and chemical processes such as volatilization, degradation, adsorption, dilution, or dispersion. These mechanisms can significantly reduce the potential impact of environmental contaminants by removing them from the matrix, destroying or deactivating them, or limiting their migration. It must be acknowledged that negative impacts are also possible, such as slow, prolonged release of compounds adsorbed to aquifer materials, or incomplete bioreduction of chlorinated organic compounds leading to production of various intermediates.

In cases where it can be demonstrated that NA mechanisms are operating to a degree, which indicates that clean-up of the contaminated matrix will occur naturally, and without adversely affecting potential human and ecological receptors, it may be possible to evoke monitored NA (MNA) as a remedial measure. The disposition toward MNA varies among agencies. The Department of the Navy and the U.S. Air Force Center for Environmental Excellence have recently published detailed guidelines for assessing MNA as a remedial alternative (Department of the Navy, 1998; Weidemeier et al., 1997). The EPA protocols regarding MNA are apparently still evolving. However, a current publication (EPA, 1993) suggests that the EPA considers MNA to be different from the "No Action" alternative, while acknowledging that they are often perceived to be the same (evaluation of the No Action alternative is required at CERCLA sites while that of MNA is not). The EPA (1993) also notes that considerable uncertainties exist regarding the effectiveness of MNA, and MNA is considered in the Superfund program on a case-by-case basis, with special permitting often required.

The primary organic constituents of interest at JPL include the chlorinated volatile organic compounds (VOCs), trichloroethene (TCE), carbon tetrachloride (CCl_4), and 1,2-dichloroethane (1,2-DCA), which under certain circumstances are known to be subject to NA mechanisms. Information regarding the extent to which perchlorate (ClO_4^-), the major inorganic constituent of interest at JPL, may subject to NA mechanisms is currently lacking, particularly with regard to *in-situ* biodegradation and adsorption. It is noted that some information suggests that ClO_4^- may be subject to biological destruction in natural systems (Herman and Frankenberger, 1998), however, specific details have yet to be established. For this Feasibility Study (FS), data from the JPL Long-Term Quarterly Monitoring Program [much of which comprised the OU-1/OU-3 Remedial Investigation (RI)] has been preliminarily evaluated to assess whether a more complete analysis may be warranted to fully assess MNA at JPL.

Assessing the efficiency of MNA requires information regarding: (1) concentrations of contaminants and daughter products in space and/or time; (2) relevant ambient geochemical conditions such as reduction/oxidation (redox) conditions in groundwater; (3) rates and direction of groundwater flow; (4) rates of contaminant biodegradation; and (5) demographic considerations such as presence of nearby receptor exposure points (Department of the Navy, 1998).

A preliminary assessment of whether NA mechanisms may be operating at the JPL site can be made by looking for: (1) consistent decreases in VOC concentrations over time at each sampling point; (2) consistent decreases in VOC concentrations over distance from upstream to downstream wells; and (3) major metabolites of degradable parent compounds present. Data from the Long-Term Quarterly Monitoring Program, which was initiated in August, 1996, (used in the JPL groundwater RI to construct plume maps) has been used in this preliminary evaluation. Because the behavior of ClO_4^- in geological systems is not well understood, and also because ClO_4^- data has been collected over a shorter time period than that of VOCs, ClO_4^- data was not evaluated.

Mechanisms of Chlorinated VOC Degradation

The general nature of physical NA mechanisms such as volatilization, adsorption, and dispersion are reasonably evident. However, degradation as it applies to chlorinated aliphatic hydrocarbons (the main constituents of interest at JPL), occurs biologically, and is fairly complex. Because of this complexity, and because this preliminary evaluation relies to some extent on evidence of biodegradation, a brief discussion of biodegradation of chlorinated VOCs is presented here.

Chlorinated VOCs in groundwater are typically degraded biologically via several mechanisms under both aerobic and anaerobic conditions as follows:

Reductive Dechlorination

The major pathway for biodegradation of TCE, and for CCl_4 is reductive dechlorination. This is a process whereby a chlorinated organic compound serves as a terminal electron acceptor during anaerobic respiration (not as a source of organic carbon). In this process, chlorine (Cl) atoms are removed from the parent compound forming less chlorinated metabolites and the chloride ion (Cl^-). In order for this process to occur, there must be an appropriate organic carbon source such as natural soil organic matter, or fuel hydrocarbons, and very low dissolved oxygen concentrations.

In general, reductive dechlorination of TCE proceeds sequentially, for example, from TCE to cis-1,2-dichloroethene (cis-1,2-DCE) + Cl^- , to vinyl chloride (VC) + Cl^- , to ethene + Cl^- , and to ethane; and from CCl_4 to chloroform (CHCl_3) + Cl^- , to dichloromethane (CH_2Cl_2) + Cl^- , to chloromethane (CH_3Cl) + Cl^- , and finally to water, carbon dioxide (CO_2) and Cl^- (Department of the Navy, 1998). While all of the above mentioned transformations are reductive in nature, cis-1,2-DCE and VC can also be degraded via oxidative processes (described below). Additionally,

although some research has suggested that other DCE isomers as well as several dichloroethane (DCA) isomers are products of reductive dechlorination of TCE (and PCE), both the Department of the Navy and the Air Force protocols consider the presence of cis-1,2-DCE and VC to be the major indicators of NA when TCE is present.

Oxidation

Oxidation of organic compounds by bacteria is the means by which heterotrophic organisms acquire energy for growth. This process occurs under aerobic conditions, with oxygen serving as the terminal electron acceptor, as well as anaerobically, with oxyanions such as nitrate (or various metals or organic compounds) serving as alternate terminal electron acceptors. Oxidation of TCE and CCl₄ as energy sources is generally not believed to occur, but as mentioned above, some lesser chlorinated compounds, including cis-1,2-DCE and VC are subject to conversion to water, CO₂, and Cl⁻ via aerobic bacterial oxidation reactions.

Co-metabolism

This is a process whereby organisms fortuitously degrade ("co-metabolize") a recalcitrant compound while growing on a structurally similar substrate. There is no energy derived from the co-metabolized compound, and no known benefit to the organism. The process is believed to occur as a result of enzymes with loose substrate specificity. The best documented example of this process is the fortuitous degradation of TCE by methane-oxidizing organisms (while growing on methane) under aerobic conditions. Because methane (or growth substrates similar to VOCs) are not expected to be present at JPL, this process is considered insignificant at JPL.

2.0 NATURAL ATTENUATION AT JPL

The following chlorinated VOCs have consistently been detected in one or more JPL monitoring wells: CCl₄, TCE, tetrachloroethene (PCE), 1,1-dichloroethane (1,1-DCA), 1,2-DCA, 1,1-dichloroethene (1,1-DCE), and chloroform. The concentrations of the above-listed chlorinated VOCs in JPL sampling wells/screens measured during the JPL Long-Term Quarterly Groundwater Monitoring Program (August/September 1996 to February/March, 1999) are provided in Table A-1. Of the compounds listed above, only CCl₄ and TCE have been measured at concentrations high enough to warrant assessment of changes over time.

Where CCl₄ and TCE are present, concentrations are generally stable or possibly decreasing slightly over time, and in some cases, fairly wide fluctuations have been observed (Table A-1). However, in on-site wells MW-7, MW-13, and MW-16, which are located near the contaminant source area, and therefore contain the highest CCl₄ and TCE levels, relatively consistent decreases are noted over time (Table A-1). Overall, these data suggest preliminarily that NA mechanisms may be operating in the JPL groundwater, but do not clearly indicate that concentrations are decreasing in all parts of the aquifer to a significant degree.

The data also suggest that there may be some reduction in CCl_4 and TCE concentrations over distance. CCl_4 levels decrease from MW-7 and MW-16, to downstream wells MW-8 and MW-24, and further, to MW-4 and MW-23, and finally to MW-5 and MW-10, which are sequentially down gradient from one another (refer to Figure 1-3, and Table A-1). This is most likely due to dilution and dispersion of contaminants as they migrate from source areas.

With regard to biodegradation of TCE and/or PCE, cis-1,2-DCE was detected only once and VC was not detected in groundwater samples during the OU-1/OU-3 RI and subsequent sampling (Foster Wheeler, 1999a; 1999b). Although the small number of 1,1-DCE, 1,1-DCA and 1,2-DCA detections may be suggestive of biodegradation, the relative absence of cis-1,2-DCE and VC indicate that if it is occurring, biodegradation of PCE and TCE is minimal.

Chloroform (the primary metabolite of CCl_4 degradation) was detected in samples from several wells that also contained CCl_4 , but it was also detected with relatively equal frequency in samples from wells where CCl_4 was not detected. More reduced products of CCl_4 degradation include dichloromethane, which was detected very infrequently during the RI, and chloromethane, which was not detected during the RI. Chloroform was detected at concentrations that were generally very low relative to those of CCl_4 , and was detected in equipment blanks with relatively high frequency. These data suggest that biodegradation of CCl_4 may be occurring, but if so, it is minimal.

To further assess the potential for degradation of organic compounds, dissolved oxygen (DO), and oxidation/reduction potential (Eh) of water sampled from JPL were measured during the February/March 1999 sampling round. These data are presented in Table A-2. DO and Eh are important indicators used to assess the potential for biodegradation of chlorinated organic compounds. According to Weidemeier et al., (1999), threshold DO and Eh values in groundwater systems are 0.5 mg/L and 50 millivolts (mV) (respectively). This information indicates that when aqueous DO and Eh levels are below these limits, biodegradation of chlorinated organic compounds is favored, whereas when DO and Eh levels exceed these limits, biodegradation is suppressed. As is evident from Table A-2, DO and Eh values in JPL groundwater were generally in excess of these threshold values, indicating conditions that suppress biodegradation of chlorinated organic compounds. These data are in agreement with data described above regarding the general absence of TCE metabolites and lack of spatial correlation of potential CCl_4 metabolites with the parent compound(s).

3.0 SUMMARY AND CONCLUSIONS

Data from the JPL Long-Term Quarterly Groundwater Monitoring Program (Tables A-1 and A-2) were used to support a preliminary analysis of whether or not NA mechanisms may be operating in the JPL aquifer. The objective of the analysis was to determine whether further investigation is warranted to assess NA as a potential remedial option for chlorinated VOCs in the JPL groundwater. Data for CCl_4 and TCE were used in this analysis because these

compounds were the frequently detected over the course of the RI, and therefore would provide the most complete picture. This assessment yielded the following observations:

- Concentrations of CCl₄ and TCE at the majority of sampling points were generally stable or slightly decreasing over time. However, potentially significant decreases were noted in the wells with the highest CCl₄ and TCE levels.
- Concentrations of CCl₄ and TCE generally decrease from up-gradient to down-gradient wells.
- Of the two primary breakdown products that would indicate biodegradation of TCE and PCE (cis-1,2-DCE and VC), only cis-1,2-DCE was detected one time. Other potential breakdown products were detected at a very low frequency.
- The primary breakdown product of CCl₄ (CHCl₃) was frequently detected, but did not appear to be well correlated with detections of CCl₄.
- Dissolved oxygen and oxidation/reduction data from analysis of JPL groundwater suggested that conditions are generally not favorable for biodegradation of chlorinated VOCs.

Based on the data and observations discussed above, it appears that biodegradation processes may be occurring, but the extent appears to be minimal. Physical processes such as dilution and dispersion, however, are likely operating, and probably account for the decreases in observed contaminant concentrations from upgradient to down-gradient wells.

Information provided here suggests that, although they may be occurring to a limited degree, NA processes would not be sufficient to provide a primary remediation mechanism. However, dilution and dispersion could provide a means to reduce VOC contaminant levels to some degree, and is probably more significant near the edges of the plumes where contaminant levels are low.

4.0 REFERENCES

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TABLES

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-1	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-3								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	1.2
	Oct/Nov 1996	--	--	--	--	--	--	8.3
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	--	--	--	--	--	--	5.5
	Oct/Nov 1996	--	--	--	--	--	--	4.8
	Feb/Mar 1997	--	--	--	--	--	--	4.4
	Jun/Jul 1997	--	--	--	--	--	--	1.2
	Sep/Oct 1997	--	--	--	--	--	--	0.8
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 3	Aug/Sep 1996	0.6	0.8	--	--	--	--	1.6
	Oct/Nov 1996	--	--	--	--	--	--	0.7
	Feb/Mar 1997	--	--	--	--	--	--	0.8
	Jun/Jul 1997	1.2	0.8	0.6	--	--	--	1.8
	Sep/Oct 1997	1.2	0.5	--	--	--	--	1.6
	Jan/Feb 1998	1.2	--	--	--	--	--	2.7
	Apr/May 1998	3.6	0.9	--	--	--	--	3.9
	Jul/Aug 1998	2.4	0.6	--	--	--	--	3.6
	Oct/Nov 1998	5.8	0.7	--	--	--	--	21
	Feb/Mar 1999	4.5	1.3	--	--	--	--	42
Screen 4	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCS DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-4								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	5.5	19	--	--	0.9	0.7	6.7
	Oct/Nov 1996	5.3	15	--	--	0.6	0.8	5.4
	Feb/Mar 1997	7.9	19	--	--	0.8	0.8	7.8
	Jun/Jul 1997	4.0	5.7	--	--	--	0.5	3.4
	Sep/Oct 1997	4.0	8.0	0.5	0.6	--	0.5	3.5
	Jan/Feb 1998	1.9	2.7	0.6	--	--	--	1.8
	Apr/May 1998	2.8	4.3	0.7	0.5	--	--	3.1
	Jul/Aug 1998	1.5	3.0	0.8	0.5	--	--	2.0
	Oct/Nov 1998	0.9	2.4	0.7	--	--	--	1.6
	Feb/Mar 1999	1.2	4.1	0.6	0.5	--	--	2.5
Screen 3	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 4	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)

(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 5	Oct/Nov 1996	--	--	--	--	--	--	--
	Aug/Sep 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-6	Aug/Sep 1996	--	--	--	--	--	--	1.3(TB)
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	0.8	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	2.0	1.0	--	--	--
	Apr/May 1998	--	0.7	3.2	1.1	--	--	0.6
	Jul/Aug 1998	--	0.6	2.5	0.8	--	--	--
	Oct/Nov 1998	--	--	0.7	--	--	--	--
	Feb/Mar 1999	--	0.8	3.8	1.0	--	--	0.6
MW-7	Aug/Sep 1996	90	39	0.8	--	1.2	1.1	13(TB)
	Oct/Nov 1996	170	27	1.3	--	0.8	2.3	14
	Feb/Mar 1997	45	27	0.6	--	0.8	0.9	9.9
	Jun/Jul 1997	39	23	0.7	--	0.8	1.0	11
	Sep/Oct 1997	93	22	1.1	--	0.9	1.3	13
	Jan/Feb 1998	150	24	3.7	--	0.8	2.1	13
	Apr/May 1998	31	13	0.5	--	--	--	6.1
	Jul/Aug 1998	43	19	0.8	--	0.6	0.9	9.0
	Oct/Nov 1998	51	18	0.9	--	0.7	1.1	9.8
	Feb/Mar 1999	49	17	0.6	--	--	0.9	7.2
MW-8	Aug/Sep 1996	4.0	4.6	--	--	--	--	1.3
	Oct/Nov 1996	2.8	2.2	--	--	--	--	0.6
	Feb/Mar 1997	1.5	4.5	--	--	--	--	1.3
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	3.2	3.6	--	--	--	--	1.2
	Jan/Feb 1998	1.8	1.3	--	--	--	--	0.8
	Apr/May 1998	1.3	1.3	--	--	--	--	0.5
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-9	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-10	Aug/Sep 1996	0.7	18	0.5	--	--	--	1.4(TB)
	Oct/Nov 1996	0.6	6.6	1.0	1.9	--	--	1.1
	Feb/Mar 1997	--	5.2	--	--	--	--	0.6
	Jun/Jul 1997	--	2.2	--	--	--	--	--
	Sep/Oct 1997	--	4.3	1.3	1.2	--	--	1.0
	Jan/Feb 1998	--	1.1	2.2	1.6	--	--	1.4
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	5.7	--	--	--	--	0.9
MW-11								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	1.4	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	1.5	--	--	--	--	--	--
	Oct/Nov 1998	1.4	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	2.4	--	--	--	--	--	1.0
	Oct/Nov 1996	1.1	--	--	--	--	--	1.2
	Feb/Mar 1997	1.7	--	--	--	--	--	1.0
	Jun/Jul 1997	1.2	--	--	--	--	--	1.0
	Sep/Oct 1997	0.6	--	--	--	--	--	0.6
	Jan/Feb 1998	0.7	--	--	--	--	--	0.7
	Apr/May 1998	1.0	--	--	--	--	--	0.7
	Jul/Aug 1998	0.9	--	--	--	--	--	0.6
	Oct/Nov 1998	0.6	--	--	--	--	--	0.7
	Feb/Mar 1999	--	--	--	--	--	--	1.1
Screen 3	Aug/Sep 1996	0.9	--	--	--	--	--	1.3
	Oct/Nov 1996	--	--	--	--	--	--	1.4
	Feb/Mar 1997	--	--	--	--	--	--	1.1
	Jun/Jul 1997	0.7	--	--	--	--	--	1.4
	Sep/Oct 1997	0.6	--	--	--	--	--	1.3
	Jan/Feb 1998	--	--	--	--	--	--	1.4
	Apr/May 1998	1.0	--	--	--	--	--	1.3
	Jul/Aug 1998	1.5	--	--	--	--	--	1.4
	Oct/Nov 1998	1.3	--	--	--	--	--	1.1
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in $\mu\text{g/L}$)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl_4	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 4	Aug/Sep 1996	--	--	--	--	--	--	0.5
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	0.5
	Apr/May 1998	--	--	--	--	--	--	0.5
	Jul/Aug 1998	--	--	--	--	--	--	0.5
	Oct/Nov 1998	--	--	--	--	--	--	0.6
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-12								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	4.1
	Oct/Nov 1996	Not Sampled*						
	Feb/Mar 1997	--	--	--	--	--	--	5.8
	Jun/Jul 1997	--	--	--	--	--	--	0.5
	Sep/Oct 1997	Not Sampled*						
	Jan/Feb 1998	--	--	--	--	--	--	0.8
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	0.9	--	--	--	--	--	--
	Oct/Nov 1996	1.5	0.6	--	--	--	--	--
	Feb/Mar 1997	1.1	0.5	--	--	--	--	--
	Jun/Jul 1997	1.0	--	--	--	--	--	0.8
	Sep/Oct 1997	0.8	--	--	--	--	--	0.8
	Jan/Feb 1998	1.1	--	--	--	--	--	0.6
	Apr/May 1998	1.2	--	--	--	--	--	0.9
	Jul/Aug 1998	1.4	--	--	--	--	--	0.9
	Oct/Nov 1998	1.3	--	--	--	--	--	1.0
	Feb/Mar 1999	1.3	--	--	--	--	--	0.9
Screen 3	Aug/Sep 1996	4.5	--	--	--	--	--	1.3
	Oct/Nov 1996	3.8	--	--	--	--	--	1.3
	Feb/Mar 1997	6.4	--	--	--	--	--	1.4
	Jun/Jul 1997	20	--	--	--	--	--	1.6
	Sep/Oct 1997	14	--	--	--	--	--	1.7
	Jan/Feb 1998	23E	--	--	--	--	--	2.3
	Apr/May 1998	25	--	--	--	--	--	2.0
	Jul/Aug 1998	35	--	--	--	--	--	2.2
	Oct/Nov 1998	27	--	--	--	--	--	2.2
	Feb/Mar 1999	23	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 4	Aug/Sep 1996	6.3	--	--	--	--	--	1.4
	Oct/Nov 1996	5.1	--	--	--	--	--	1.4
	Feb/Mar 1997	4.9	--	--	--	--	--	1.3
	Jun/Jul 1997	4.9	--	--	--	--	--	1.3
	Sep/Oct 1997	3.8	--	--	--	--	--	1.0
	Jan/Feb 1998	4.0	--	--	--	--	--	1.1
	Apr/May 1998	4.3	--	--	--	--	--	1.2
	Jul/Aug 1998	5.1	--	--	--	--	--	1.2
	Oct/Nov 1998	4.1	--	--	--	--	--	1.2
	Feb/Mar 1999	4.5	--	--	--	--	--	1.2
Screen 5	Aug/Sep 1996	3.4	--	--	--	--	--	0.7
	Oct/Nov 1996	1.3	--	--	--	--	--	--
	Feb/Mar 1997	1.7	--	--	--	--	--	0.5
	Jun/Jul 1997	1.9	--	--	--	--	--	0.5
	Sep/Oct 1997	1.3	--	--	--	--	--	--
	Jan/Feb 1998	1.3	--	--	--	--	--	--
	Apr/May 1998	1.7	--	--	--	--	--	0.6
	Jul/Aug 1998	2.1	--	--	--	--	--	0.6
	Oct/Nov 1998	2.0	--	--	--	--	--	0.6
	Feb/Mar 1999	1.3	--	--	--	--	--	0.7
MW-13	Aug/Sep 1996	21	47	0.6	--	2.5	1.5	21(TB)
	Oct/Nov 1996	27	27	--	--	1.9	1.5	14
	Feb/Mar 1997	18	28	--	--	0.9	1.1	9.2
	Jun/Jul 1997	6.4	24 E	--	--	0.9	0.5	11
	Sep/Oct 1997	8.2	19	--	--	1.1	0.5	10
	Jan/Feb 1998	12	5.2	0.5	--	--	0.5 (DUP 2)	2.9
	Apr/May 1998	13	17	0.6	--	--	0.9	5.7
	Jul/Aug 1998	15	29	0.6	--	--	1.2	7.7
	Oct/Nov 1998	9.01	20	--	--	--	1.1	9.3
	Feb/Mar 1999	9.4	28	--	--	0.7	0.7	--
MW-14								
Screen 1	Aug/Sep 1996	--	--	--	2.4	--	--	0.6
	Oct/Nov 1996	--	--	--	2.9	--	--	--
	Feb/Mar 1997	--	--	0.7	1.5	--	--	0.7
	Jun/Jul 1997	--	--	--	2.0	--	--	--
	Sep/Oct 1997	--	--	--	1.9	--	--	--
	Jan/Feb 1998	--	--	--	2.1	--	--	0.5
	Apr/May 1998	--	--	1.2	0.8	--	--	0.8
	Jul/Aug 1998	--	--	0.8	1.7	--	--	0.6
	Oct/Nov 1998	--	--	0.5	2.4	--	--	0.6
	Feb/Mar 1999	--	--	0.8	1.2	--	--	0.6
Screen 2	Aug/Sep 1996	--	2.8	1.6	1.4	--	--	1.5
	Oct/Nov 1996	--	1.5	1.6	1.0	--	--	0.9
	Feb/Mar 1997	--	0.9	1.9	1.3	--	--	0.8
	Jun/Jul 1997	--	1.1	1.7	1.5	--	--	0.9
	Sep/Oct 1997	--	1.2	1.9	1.6	--	--	0.8
	Jan/Feb 1998	--	--	1.2	0.7	--	--	--
	Apr/May 1998	--	--	1.2	0.7	--	--	0.6
	Jul/Aug 1998	--	0.9	1.8	0.8	--	--	0.6
	Oct/Nov 1998	--	0.6	1.5	0.7	--	--	0.5
	Feb/Mar 1999	--	0.9	1.6	0.7	--	--	0.6

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in $\mu\text{g/L}$)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl_4	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 3	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	0.5	--	--	--	0.5
Screen 4	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-15	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-16	Aug/Sep 1996	125	33	1.3	--	2.4	2.2	40(TB)
	Oct/Nov 1996	Not Sampled*						
	Feb/Mar 1997	91	23	1.3	--	1.7	2.6	29
	Jun/Jul 1997	68	25	1.1	--	2.1	1.7	43
	Sep/Oct 1997	Not Sampled*						
	Jan/Feb 1998	30	3.5	1.0	--	--	1.3	14
	Apr/May 1998	42	12	0.8	--	1.4	1.6	20
	Jul/Aug 1998	58	19	1.3	--	0.8	2.7	23
	Oct/Nov 1998	51	18	1.0	--	1.5	1.6	29
	Feb/Mar 1999	67	20	1.4	--	1.1	1.8	24

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)

(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-17								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	2.9
	Apr/May 1998	--	--	--	--	--	--	3.2
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	--	--	--	--	--	--	3.8
	Oct/Nov 1996	--	--	--	--	--	--	6.0
	Feb/Mar 1997	--	--	--	--	--	--	5.2
	Jun/Jul 1997	--	--	--	--	--	--	4.1
	Sep/Oct 1997	--	--	--	--	--	--	6.1
	Jan/Feb 1998	--	--	--	--	--	--	5.4
	Apr/May 1998	--	--	--	--	--	--	3.2
	Jul/Aug 1998	--	--	--	--	--	--	2.4
	Oct/Nov 1998	--	--	--	--	--	--	3.7
	Feb/Mar 1999	--	--	--	--	--	--	3.9
Screen 3	Aug/Sep 1996	2.0	7.9	--	--	--	--	7.5
	Oct/Nov 1996	3.3	18	0.8	--	--	--	8.7
	Feb/Mar 1997	5.1	23	1.1	--	--	--	6.2
	Jun/Jul 1997	1.3	5.9	--	--	--	--	8.2
	Sep/Oct 1997	6.6	22	1.4	--	--	--	9.2
	Jan/Feb 1998	3.3	8.7	--	--	--	--	6.8
	Apr/May 1998	--	0.9	--	--	--	--	5.3
	Jul/Aug 1998	--	1.0	--	--	--	--	4.9
	Oct/Nov 1998	--	1.9	--	--	--	--	4.1
	Feb/Mar 1999	--	1.6	--	--	--	--	3.8
Screen 4	Aug/Sep 1996	--	9.5	0.5	--	--	--	1.1
	Oct/Nov 1996	--	8.9	--	--	--	--	1.5
	Feb/Mar 1997	--	5.8	--	--	--	--	0.7
	Jun/Jul 1997	--	4.5	--	--	--	--	0.6
	Sep/Oct 1997	--	6.8	0.5	--	--	--	1.0
	Jan/Feb 1998	--	7.3	0.6	--	--	--	1.2
	Apr/May 1998	--	7.6	0.6	--	--	--	1.5
	Jul/Aug 1998	--	8.9	0.6	--	--	--	1.9
	Oct/Nov 1998	--	6.2	0.5	--	--	--	1.9
	Feb/Mar 1999	--	3.8	--	--	--	--	1.8
Screen 5	Aug/Sep 1996	--	13	0.6	--	--	--	1.7
	Oct/Nov 1996	--	16	0.7	--	--	--	1.7
	Feb/Mar 1997	--	14	0.7	--	--	--	1.3
	Jun/Jul 1997	--	11	0.7	--	--	--	1.3
	Sep/Oct 1997	--	8.6	0.6	--	--	--	1.4
	Jan/Feb 1998	--	7.9	--	--	--	--	1.5
	Apr/May 1998	--	8.8	0.6	--	--	--	1.8
	Jul/Aug 1998	--	8.9	0.6	--	--	--	2.0
	Oct/Nov 1998	--	11	0.8	--	--	--	2.7
	Feb/Mar 1999	--	4.9	--	--	--	--	2.1

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**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in $\mu\text{g/L}$)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-18								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	1.6
	Oct/Nov 1996	Not Sampled*						
	Feb/Mar 1997	--	--	--	--	--	--	3.0
	Jun/Jul 1997	--	--	--	--	--	--	0.8
	Sep/Oct 1997	Not Sampled*						
	Jan/Feb 1998	Not Sampled*						
	Apr/May 1998	--	--	--	--	--	--	0.7
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 2	Aug/Sep 1996	--	--	--	--	--	--	7.3
	Oct/Nov 1996	--	--	--	--	--	--	8.2
	Feb/Mar 1997	--	--	--	--	--	--	1.9
	Jun/Jul 1997	--	--	--	--	--	--	4.5
	Sep/Oct 1997	--	--	--	--	--	--	2.5
	Jan/Feb 1998	--	--	--	--	--	--	3.7
	Apr/May 1998	--	--	--	--	--	--	3.2
	Jul/Aug 1998	--	--	--	--	--	--	0.9
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	3.0
Screen 3	Aug/Sep 1996	0.7	4.7	2.8	--	--	--	5.1
	Oct/Nov 1996	0.7	6.4	3.2	--	--	--	5.6
	Feb/Mar 1997	0.8	6.6	2.9	--	--	--	5.1
	Jun/Jul 1997	0.6	2.4	1.8	--	--	--	4.4
	Sep/Oct 1997	--	3.0	1.9	--	--	--	6.2
	Jan/Feb 1998	--	1.9	1.7	--	--	--	6.6
	Apr/May 1998	0.5	1.8	1.3	--	--	--	5.7
	Jul/Aug 1998	--	1.5	0.9	--	--	--	4.6
	Oct/Nov 1998	--	1.4	0.8	--	--	--	4.2
	Feb/Mar 1999	--	1.0	0.5	--	--	--	3.5
Screen 4	Aug/Sep 1996	2.2	--	0.7	--	--	--	0.5
	Oct/Nov 1996	2.2	--	0.7	--	--	--	0.5
	Feb/Mar 1997	2.2	--	1.5	--	--	--	0.6
	Jun/Jul 1997	1.9	--	0.7	--	--	--	--
	Sep/Oct 1997	2.4	--	0.7	--	--	--	--
	Jan/Feb 1998	2.6	--	1.0	--	--	--	0.5
	Apr/May 1998	3.1	0.6	1.4	--	--	--	0.8
	Jul/Aug 1998	2.5	0.6	1.2	--	--	--	0.6
	Oct/Nov 1998	3.4	0.8	1.5	--	--	--	0.7
	Feb/Mar 1999	4.7	1.2	2.3	--	--	--	1.1
Screen 5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
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(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-19								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	0.9
	Oct/Nov 1996	--	--	--	--	--	--	0.6
	Feb/Mar 1997	--	--	--	--	--	--	0.8
	Jun/Jul 1997	--	--	--	--	--	--	2.5
	Sep/Oct 1997	--	--	--	--	--	--	1.4
	Jan/Feb 1998	--	--	--	--	--	--	0.8
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
Screen 2	Feb/Mar 1999	--	--	--	--	--	--	--
	Aug/Sep 1996	--	--	0.8	--	--	--	--
	Oct/Nov 1996	--	--	1.1	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	0.6	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	0.6	0.9	--	--	--	--
	Apr/May 1998	--	0.9	1.2	--	--	--	--
	Jul/Aug 1998	--	0.6	0.7	--	--	--	--
Screen 3	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	0.6	--	--	--	--	--
	Aug/Sep 1996	--	--	3.1	--	--	--	--
	Oct/Nov 1996	--	--	2.5	--	--	--	--
	Feb/Mar 1997	--	--	2.1	--	--	--	--
	Jun/Jul 1997	--	--	2.0	--	--	--	--
	Sep/Oct 1997	--	--	1.5	--	--	--	--
	Jan/Feb 1998	--	--	2.1	--	--	--	--
	Apr/May 1998	--	--	2.5	--	--	--	--
Screen 4	Jul/Aug 1998	--	--	2.1	--	--	--	--
	Oct/Nov 1998	--	--	2.0	--	--	--	--
	Feb/Mar 1999	--	--	1.5	--	--	--	--
	Aug/Sep 1996	0.5	1.5	--	--	--	--	2.1
	Oct/Nov 1996	--	1.5	--	--	--	--	1.9
	Feb/Mar 1997	--	1.1	0.6	--	--	--	1.5
	Jun/Jul 1997	--	0.7	--	--	--	--	1.3
	Sep/Oct 1997	--	0.7	0.6	--	--	--	1.7
	Jan/Feb 1998	--	0.5	0.6	--	--	--	1.3
Screen 5	Apr/May 1998	--	0.8	1.0	--	--	--	1.6
	Jul/Aug 1998	--	--	--	--	--	--	1.4
	Oct/Nov 1998	--	--	--	--	--	--	2.2
	Feb/Mar 1999	--	--	--	--	--	--	3.0
	Aug/Sep 1996	--	--	3.0	--	--	--	0.6
	Oct/Nov 1996	--	--	2.4	--	--	--	--
	Feb/Mar 1997	--	--	1.7	--	--	--	--
	Jun/Jul 1997	--	--	1.5	--	--	--	--
	Sep/Oct 1997	--	--	2.2	--	--	--	0.8
Screen 5	Jan/Feb 1998	--	--	1.4	--	--	--	--
	Apr/May 1998	--	--	0.9	--	--	--	0.6
	Jul/Aug 1998	--	--	1.5	--	--	--	--
	Oct/Nov 1998	--	--	1.5	--	--	--	--
	Feb/Mar 1999	--	--	1.3	--	--	--	--

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(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-20								
Screen 1	Aug/Sep 1996	--	--	--	--	--	--	0.7
	Oct/Nov 1996	Not Sampled*						
	Feb/Mar 1997	--	--	--	--	--	--	1.4
	Jun/Jul 1997	--	--	--	--	--	--	0.8
	Sep/Oct 1997	Not Sampled*						
	Jan/Feb 1998	--	--	--	--	--	--	1.4
	Apr/May 1998	--	--	--	--	--	--	2.5
	Jul/Aug 1998	--	--	--	--	--	--	1.8
	Oct/Nov 1998	--	--	--	--	--	--	0.8
	Feb/Mar 1999	--	--	--	--	--	--	2.2
Screen 2	Aug/Sep 1996	--	--	--	--	--	--	7.7
	Oct/Nov 1996	--	--	--	--	--	--	4.4
	Feb/Mar 1997	--	--	--	--	--	--	3.2
	Jun/Jul 1997	--	--	--	--	--	--	3.3
	Sep/Oct 1997	--	--	--	--	--	--	5.7
	Jan/Feb 1998	--	--	--	--	--	--	2.7
	Apr/May 1998	--	--	--	--	--	--	2.7
	Jul/Aug 1998	--	--	--	--	--	--	4.2
	Oct/Nov 1998	--	--	--	--	--	--	3.6
	Feb/Mar 1999	--	--	--	--	--	--	4.2
Screen 3	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	0.6
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 4	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Aug/Sep 1996	--	--	--	--	--	--	--
	Oct/Nov 1996	--	--	--	--	--	--	--
	Feb/Mar 1997	--	--	--	--	--	--	--
	Jun/Jul 1997	--	--	--	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-21								
Screen 1	Aug/Sep 1996	--	33	0.7	--	--	--	1.8
	Oct/Nov 1996	Not Sampled*						
	Feb/Mar 1997	--	29	--	--	--	--	2.2
	Jun/Jul 1997	--	20	--	--	--	--	1.6
	Sep/Oct 1997	Not Sampled*						
	Jan/Feb 1998	--	16	--	--	--	--	1.8
	Apr/May 1998	--	16	--	--	--	--	1.8
	Jul/Aug 1998	--	16	0.6	--	--	--	1.8
	Oct/Nov 1998	--	10	--	--	--	--	1.6
	Feb/Mar 1999	--	20	0.5	--	--	--	1.8
Screen 2	Aug/Sep 1996	--	--	0.9	--	--	--	0.5
	Oct/Nov 1996	--	0.6	2.3	--	--	--	0.6
	Feb/Mar 1997	--	--	1.1	--	--	--	--
	Jun/Jul 1997	--	--	0.7	--	--	--	--
	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	1.1	--	--	--	--
	Apr/May 1998	--	--	1.0	--	--	--	--
	Jul/Aug 1998	--	--	0.7	--	--	--	0.7
	Oct/Nov 1998	--	--	--	--	--	--	0.7
	Feb/Mar 1999	--	--	0.8	--	--	--	--
Screen 3	Aug/Sep 1996	--	0.7	1.5	--	--	--	0.5
	Oct/Nov 1996	--	0.9	1.6	--	--	--	--
	Feb/Mar 1997	--	0.8	1.6	--	--	--	--
	Jun/Jul 1997	--	--	1.2	--	--	--	--
	Sep/Oct 1997	--	0.6	1.3	--	--	--	--
	Jan/Feb 1998	--	0.5	1.4	--	--	--	--
	Apr/May 1998	--	--	1.1	--	--	--	--
	Jul/Aug 1998	--	--	0.9	--	--	--	--
	Oct/Nov 1998	--	--	0.8	--	--	--	--
	Feb/Mar 1999	--	--	1.0	--	--	--	--
Screen 4	Aug/Sep 1996	--	0.8	4.2	--	--	--	--
	Oct/Nov 1996	--	--	2.5	--	--	--	--
	Feb/Mar 1997	--	--	1.8	--	--	--	--
	Jun/Jul 1997	--	--	2.8	--	--	--	--
	Sep/Oct 1997	--	0.6	4.4	--	--	--	--
	Jan/Feb 1998	--	--	2.4	--	--	--	--
	Apr/May 1998	--	0.6	4.4	--	--	--	--
	Jul/Aug 1998	--	0.8	4.3	--	--	--	--
	Oct/Nov 1998	--	1.1	8.3	--	--	--	0.6
	Feb/Mar 1999	--	--	3.8	--	--	--	--
Screen 5	Aug/Sep 1996	--	--	4.5	--	--	--	0.6
	Oct/Nov 1996	--	--	3.1	--	--	--	--
	Feb/Mar 1997	--	--	3.0	--	--	--	--
	Jun/Jul 1997	--	--	3.0	--	--	--	--
	Sep/Oct 1997	--	--	2.9	--	--	--	--
	Jan/Feb 1998	--	--	4.1	--	--	--	--
	Apr/May 1998	--	--	6.5	--	--	--	--
	Jul/Aug 1998	--	--	7.6	--	--	--	0.6
	Oct/Nov 1998	--	--	6.7	--	--	--	0.6
	Feb/Mar 1999	--	0.5	7.7	--	--	--	0.7

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
MW-22(1)								
Screen 1	Sep/Oct 1997	--	--	2.0	0.7	--	--	--
	Jan/Feb 1998	--	--	2.3	0.8	--	--	--
	Apr/May 1998	--	0.9	2.1	0.8	--	--	0.5
	Jul/Aug 1998	--	0.9	1.7	0.6	--	--	--
	Oct/Nov 1998	--	--	1.7	0.7	--	--	--
	Feb/Mar 1999	--	0.6	3.6	1.0	--	--	0.5
Screen 2	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	0.6	--	--	--	--	--
Screen 3	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 4	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-23(1)								
Screen 1	Sep/Oct 1997	--	3.1	0.6	0.8	--	--	--
	Jan/Feb 1998	--	4.2	1.6	1.2	--	--	0.9
	Apr/May 1998	0.5	16	0.8	1.2	--	--	1.9
	Jul/Aug 1998	0.5	9.2	--	--	--	--	1.0
	Oct/Nov 1998	0.8	15	--	--	--	--	1.9
	Feb/Mar 1999	0.6	15	1.1	1.4	--	--	1.9
Screen 2	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	0.7
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	1.1	1.0	0.8	--	--	0.7
	Oct/Nov 1998	--	0.6	0.7	0.6	--	--	0.6
	Feb/Mar 1999	--	--	--	--	--	--	0.5
Screen 3	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in µg/L)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Screen 4	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
MW-24(1)								
Screen 1	Sep/Oct 1997	5.0	5.0	--	--	--	--	3.1
	Jan/Feb 1998	30E	15	0.5	--	0.8	--	15
	Apr/May 1998	6.7	5.4	--	--	--	--	3.3
	Jul/Aug 1998	--	1.7	--	--	--	--	0.9
	Oct/Nov 1998	1.0	1.3	--	--	--	--	0.8
	Feb/Mar 1999	1.0	1.5	--	--	--	--	0.8
Screen 2	Sep/Oct 1997	13	1.3	--	--	--	--	3.8
	Jan/Feb 1998	6.9	0.7	--	--	--	--	2.4
	Apr/May 1998	29	3.3	0.9	--	--	1.4	9.4
	Jul/Aug 1998	58	4.0	1.5	--	--	2.0	8.4
	Oct/Nov 1998	19	2.3	0.8	--	--	0.8	5.9
	Feb/Mar 1999	30E	3.0	1.0	--	--	1.5	6.6
Screen 3	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 4	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--
Screen 5	Sep/Oct 1997	--	--	--	--	--	--	--
	Jan/Feb 1998	--	--	--	--	--	--	--
	Apr/May 1998	--	--	--	--	--	--	--
	Jul/Aug 1998	--	--	--	--	--	--	--
	Oct/Nov 1998	--	--	--	--	--	--	--
	Feb/Mar 1999	--	--	--	--	--	--	--

TABLE A-1

**SUMMARY OF SELECTED CHLORINATED VOCs DETECTED DURING THE JPL
LONG-TERM QUARTERLY MONITORING PROGRAM**

(Concentrations in $\mu\text{g/L}$)
(Source: Foster Wheeler, 1999b)

Sampling Location	Sampling Event	CCl ₄	TCE	PCE	1,1-DCA	1,2-DCA	1,1-DCE	Total Trihalomethanes (Primarily Chloroform)
Practical Quantitation Limit		0.5	0.5	0.5	0.5	0.5	0.5	0.5
California Maximum Contaminant Level		0.5	5.0	5.0	5.0	0.5	6.0	100
EPA Region IX Maximum Contaminant Level		5.0	5.0	5.0	NE	5.0	7.0	100

Notes:

- : Not detected.
- *: Not sampled, no water over screen.
- a: Only VOCs for which MCLs have been established are listed.
- TB: Compound detected in associated trip blank.
- E: Estimated concentration; result exceeded calibration range.
- NA: Not analyzed.
- NE: Not established.
- (1): Wells installed June-August 1997.
- (2): DUP – Results from duplicate analysis; original sample was non-detect.

TABLE A-2
SUMMARY OF FIELD DATA OF GROUNDWATER SAMPLES
COLLECTED FROM JPL MONITORING WELLS
AUGUST 1999

Well Number	pH	Temperature (°C)	Conductivity (µmhos) ⁽¹⁾	Dissolved Oxygen (mg/L) ⁽²⁾	E _h (mV) ⁽³⁾
MW-1	-	-	-	-	-
MW-3					
Screen 1	-	-	-	-	-
Screen 2	7.83	24.8	459	5.52	231
Screen 3	8.21	25.2	464	5.63	231
Screen 4	8.31	25.1	360	6.06	231
Screen 5	9.23	22.7	317	6.12	231
MW-4					
Screen 1	7.07	20.2	380	4.01	231
Screen 2	7.14	21.1	640	6.06	231
Screen 3	8.09	21.6	375	4.42	231
Screen 4	7.92	21.5	365	6.18	231
Screen 5	7.27	21.1	364	7.15	231
MW-5	6.79	19.2	356	3.39	231
MW-6	6.88	24.9	772	5.59	231
MW-7	7.40	23.7	491	6.01	231
MW-8	7.15	24.5	357	4.86	231
MW-9	-	-	-	-	-
MW-10	6.74	20.5	583	4.57	231
MW-11					
Screen 1	7.77	21.1	462	3.79	231
Screen 2	7.96	20.0	412	3.60	231
Screen 3	8.12	20.1	380	5.39	231
Screen 4	8.17	18.8	330	6.17	231
Screen 5	-	-	-	-	-
MW-12					
Screen 1	7.64	22.9	416	4.39	231
Screen 2	7.44	20.1	465	5.71	231
Screen 3	6.99	21.4	461	5.78	231
Screen 4	7.01	20.0	429	6.42	231
Screen 5	7.48	20.0	400	7.41	231
MW-13	7.12	23.6	582	6.36	231

TABLE A-2
SUMMARY OF FIELD DATA OF GROUNDWATER SAMPLES
COLLECTED FROM JPL MONITORING WELLS
AUGUST 1999

Well Number	pH	Temperature (°C)	Conductivity (µmhos) ⁽¹⁾	Dissolved Oxygen (mg/L) ⁽²⁾	E _h (mV) ⁽³⁾
MW-14					
Screen 1	7.14	24.1	1338	5.83	231
Screen 2	7.03	22.7	1204	5.87	231
Screen 3	7.75	22.2	959	5.12	231
Screen 4	7.91	21.3	544	6.98	231
Screen 5	8.61	20.5	297	6.45	231
MW-15					
	-	-	-	-	-
MW-16					
	7.09	24.3	581	5.65	231
MW-17					
Screen 1	-	-	-	-	-
Screen 2	8.15	20.2	306	5.21	231
Screen 3	7.65	20.4	380	5.23	231
Screen 4	7.68	22.9	418	7.13	231
Screen 5	7.94	18.1	373	5.69	231
MW-18					
Screen 1	6.52	21.3	253	5.84	231
Screen 2	6.63	21.6	392	5.97	231
Screen 3	7.23	20.4	433	5.19	231
Screen 4	7.26	21.1	382	6.46	231
Screen 5	8.11	21.6	279	7.12	231
MW-19					
Screen 1	7.40	24.1	311	4.54	231
Screen 2	6.75	23.6	576	4.47	231
Screen 3	7.05	21.9	896	6.11	231
Screen 4	7.53	23.2	468	6.31	231
Screen 5	7.63	20.8	767	4.24	231
MW-20					
Screen 1	7.38	22.7	759	6.26	231
Screen 2	7.71	21.4	378	6.47	231
Screen 3	8.16	20.2	504	6.69	231
Screen 4	8.66	19.9	309	7.11	231
Screen 5	8.70	19.4	303	6.88	231

TABLE A-2
SUMMARY OF FIELD DATA OF GROUNDWATER SAMPLES
COLLECTED FROM JPL MONITORING WELLS
AUGUST 1999

Well Number	pH	Temperature (°C)	Conductivity (µmhos) ⁽¹⁾	Dissolved Oxygen (mg/L) ⁽²⁾	E _h (mV) ⁽³⁾
MW-21					
Screen 1	6.71	19.0	789	3.84	231
Screen 2	7.57	18.8	988	2.68	231
Screen 3	7.27	18.9	896	4.38	231
Screen 4	7.26	18.9	743	6.01	231
Screen 5	7.59	18.8	736	6.52	231
MW-22					
Screen 1	6.52	20.8	990	4.60	231
Screen 2	7.11	21.2	644	5.31	231
Screen 3	7.44	20.4	473	7.15	231
Screen 4	7.63	20.3	341	7.58	231
Screen 5	-	-	-	-	-
MW-23					
Screen 1	6.81	24.7	1146	5.63	231
Screen 2	7.17	23.1	1020	5.79	231
Screen 3	7.65	22.7	474	6.41	231
Screen 4	7.87	22.3	359	6.48	231
Screen 5	9.49	22.8	550	5.29	231
MW-24					
Screen 1	7.50	24.5	420	5.72	231
Screen 2	8.16	24.2	385	5.76	231
Screen 3	7.63	23.6	441	6.41	231
Screen 4	8.49	22.2	332	6.12	231
Screen 5	-	-	-	-	-

Notes:

- (1): Not temperature corrected.
 (2): Dissolved oxygen values are adjusted to reflect concentrations at 25°C.
 (3): These values include a reference correction ($E_h = E_{meas} + E_{ref}$), $E_{ref} = +231$ mV.

APPENDIX B

APPENDIX B-1

GEOCHEMICAL PROPERTIES OF PERCHLORATE, REGULATORY ISSUES, AND POTENTIAL REMOVAL TECHNOLOGIES FOR TREATING PERCHLORATE-IMPACTED GROUNDWATER

APPENDIX B-2

INVESTIGATION AND BENCH-SCALE TREATABILITY STUDIES TO EVALUATE REMOVAL OF PERCHLORATE FROM JPL GROUNDWATER

APPENDIX B-1

GEOCHEMICAL PROPERTIES OF PERCHLORATE, REGULATORY ISSUES, AND POTENTIAL REMOVAL TECHNOLOGIES FOR TREATING PERCHLORATE-IMPACTED GROUNDWATER

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APPENDIX B-1

GEOCHEMICAL PROPERTIES OF PERCHLORATE, REGULATORY ISSUES, AND POTENTIAL REMOVAL TECHNOLOGIES FOR TREATING PERCHLORATE-IMPACTED GROUNDWATER

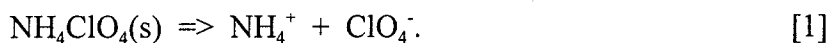
1.0 INTRODUCTION

Perchlorate (ClO_4^-) was detected in groundwater at the Jet Propulsion Laboratory (JPL) and in downgradient municipal production wells during the OU-1/OU-3 Remedial Investigation (RI), and has become a major focus with regard to the feasibility study. The identification of ClO_4^- as an environmental contaminant has occurred relatively recently (due to refinements in analytical methodology) and therefore, reliable information regarding the environmental chemistry of ClO_4^- , its behavior in soil/water systems, and technologies for treating ClO_4^- -impacted water are generally lacking. Unlike volatile organic compounds (VOCs) detected at the JPL site (carbon tetrachloride, trichloroethene, etc.) ClO_4^- is not volatile, and therefore can not be removed by air stripping or activated carbon treatment. It is becoming increasingly apparent that removal of ClO_4^- from groundwater presents formidable challenges in terms of both economic and technical feasibility.

Appendix B is intended to address some of the general issues pertaining to ClO_4^- in the environment (Appendix B-1), and to present the results of JPL's early investigations toward finding a method to treat ClO_4^- in groundwater (Appendix B-2). Accordingly, Appendix B-1 contains a summary of current information regarding: (1) chemical characteristics and environmental behavior of ClO_4^- , (2) toxicology and regulation of ClO_4^- in groundwater, and (3) remediation and treatment of ClO_4^- -impacted groundwater. Appendix B-2 presents the results of JPL's initial bench-scale treatability studies to evaluate removal of ClO_4^- from groundwater.

2.0 CHEMICAL CHARACTERISTICS AND ENVIRONMENTAL BEHAVIOR OF PERCHLORATE

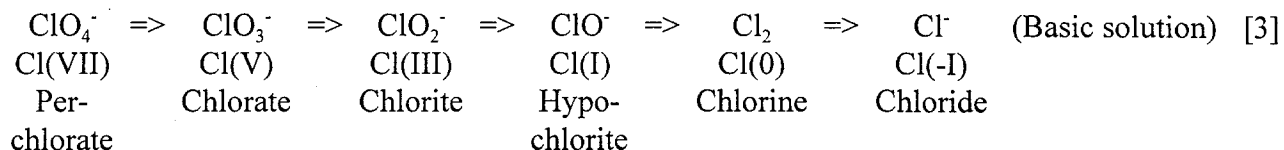
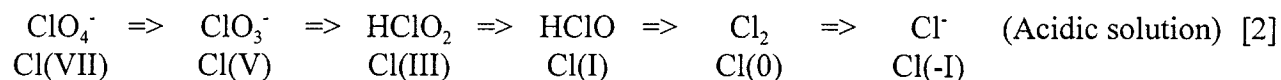
Perchlorate comprises the anionic portion of dissolved perchlorate salts such as ammonium perchlorate and sodium perchlorate (NH_4ClO_4 and NaClO_4 , respectively), which are commonly associated with the manufacture and use of propellants, explosives, and pyrotechnics (Urbanski, 1988). These salts are highly soluble and dissociate completely upon dissolving in water as illustrated by the following example (Urbanski, 1998):



Perchlorate is an oxyanion of the element chlorine (Cl). Speciation and oxidation states of Cl, including its oxyanionic forms, are given below (Ebbing, 1987):

OXIDIZED

REDUCED



The most stable Cl species/compounds are those in which the element is in its highest or lowest oxidation state (Greenwood and Earnshaw, 1985). As indicated above, ClO_4^- contains Cl in its highest oxidation state. While ClO_4^- is a powerful oxidizing agent when heated, at room temperature (typical of groundwater temperatures), aqueous solutions of ClO_4^- are not notable oxidizers and are extremely stable (Greenwood and Earnshaw, 1985).

Although (as mentioned) available information regarding the behavior of ClO_4^- in environmental matrices is limited, based on its solubility, its purported stability, and its anionic nature, ClO_4^- is considered to be persistent and very mobile in soil/water systems. This is supported by data showing its presence in water long after discharge was known to occur (Urbanski, 1998). Some research (van Ginkel, 1997) suggests that bacteria which are able to reduce ClO_4^- (under conditions where oxygen is absent or limited) to more innocuous forms such as Cl^- may be widespread in nature. This may provide a natural, in-situ mechanism for destruction of ClO_4^- in cases where an appropriate carbon (energy) source and other nutrients were available. However, in many groundwater environments, carbon (as an energy source) is typically limiting.

3.0 TOXICITY AND REGULATION PERCHLORATE

Studies cited by the California Department of Health Services (CA DHS) indicate that the primary mechanism of toxicity in humans appears to be the inhibition of iodine uptake by the thyroid gland, leading to decreased production of thyroid hormones (CA DHS, 1997). Although no Federal or State drinking water standards currently exist for ClO_4^- , the CA DHS has recommended an interim action level (IAL) of 18 $\mu\text{g/L}$, which is considered to be protective of public health (CA DHS, 1997).

The IAL was generated using toxicity data from an acute study in which single doses of potassium perchlorate caused the release of iodide from the thyroids of patients with Graves' Disease. Ideally, action levels are based on a database that allows for a more complete assessment over a variety of scenarios. Because toxicity data for ClO_4^- is lacking, new studies were begun in 1997 and are nearing conclusion to provide a more complete data set. The National Center for Environmental Assessment (NCEA) in the Office of Research and Development (ORD) of the EPA had planned to evaluate these new data and issue a new

assessment at the end of September 1998. The new assessment, including all the new data and the study protocols were then to be subjected to an external peer review in November 1998 before the assessment is finalized. At present, the new data are still in review and the IAL of 18 µg/L is still in effect.

4.0 REMEDIATION AND TREATMENT OF ClO_4^- -IMPACTED GROUNDWATER

It appears at this time that pump and treat processes may offer the only workable option for treating ClO_4^- -impacted groundwater in deep aquifers as is observed at JPL. Several techniques that are amenable to pump and treat systems may have the potential to remove ClO_4^- from water, or convert it to less toxic forms. Three basic removal techniques are currently considered applicable: reduction (biological and non-biological), adsorption, and membrane separation, all of which have been tested at the bench or small field scale for this FS. Following are brief discussions of each of these technologies as they apply to treating ClO_4^- -contaminated water at JPL (further details can be found in the respective appendices).

Reduction

Complete reduction of ClO_4^- to Cl^- represents destruction of ClO_4^- , and effectively eliminates its toxicity. Reduction of ClO_4^- may occur through biological or chemical (non-biological) reaction mechanisms. Both chemical and biological reduction mechanisms are widely used in water treatment.

Chemical Reduction

Chemical reductants can only be used to treat drinking water in cases where the reaction is rapid, they are easy to remove, are not a potential threat themselves, or can be effective when added at very low concentrations (below their regulatory limits). Various chemical reductants (soluble and insoluble) have been used in reducing oxyanions in contaminated water. For example, removal of aqueous chromate (CrO_4^{2-}) has been accomplished through reduction by soluble Fe(II) (Eary and Rai, 1988). In addition, a study recently conducted has demonstrated reduction (and removal from solution) of CrO_4^{2-} and selenate (SeO_4^{2-}) by a treatment system which utilizes insoluble, zero-valent iron (Fe^0) as the reductant (C. Amrhein, Professor of Soil Chemistry, University of California, Riverside, personal communication).

When ClO_4^- was first detected in JPL groundwater, JPL funded several initial ClO_4^- treatment studies, one of which evaluated various soluble and insoluble chemical reductants for their ability to reduce ClO_4^- in the JPL groundwater matrix (described in Appendix B-2). Results of this study suggested that none of the reductants were able to remove ClO_4^- from solution in the time frame of interest. Other reports are in agreement with the findings of the JPL study, suggesting that while in many cases reduction of ClO_4^- is thermodynamically favored, the reaction is simply too slow to be of use in remediation systems (Urbanski, 1998). Several electrolytic and photoelectrolytic reduction methods are also potentially applicable (Theis et al., 1999), but have

not been tested and are currently not considered economically feasible at the high flow rates required by JPL.

Biological Reduction

Bioreduction represents another mechanism for bringing about reduction (and hence destruction) of oxidized Cl species. This does not refer to degradative processes whereby organic contaminants such as petroleum hydrocarbons are utilized as carbon/energy sources. Rather, ClO_4^- may serve as a terminal electron acceptor in microbial respiration as O_2 becomes limiting, analogous to NO_3^- and SO_4^{2-} reduction in soils and water. Because many of these mechanisms are enzymatic in nature, reaction rates can be rapid. Several bacterial isolates with the ability to reduce ClO_4^- to Cl^- have recently been isolated (Herman and Frankenberger, 1999; Logan, 1999; Wallace et al., 1996), and bioreactor systems have been optimized to reduce ClO_4^- in groundwater (Girard, 1999), and industrial waste streams (Coppola and Baxley, 1999).

Bench scale studies were conducted to evaluate biological reduction of ClO_4^- in JPL groundwater using two bioreactor configurations: a (fluidized bed reactor (FBR), and a packed bed reactor (PBR). Based on these studies and other available information, it is believed that JPL groundwater can be treated biologically for ClO_4^- to non-detect levels (see Appendices D and E).

Biological reduction is considered the most economically feasible, and easiest way to remove ClO_4^- from groundwater (Urbanski, 1998). The major advantage is that ClO_4^- is destroyed, and no toxic by-products are formed. However, bioreactor size and process predictability are potential issues, particularly where very high flow rates are required. The issue of disposal of treated water also needs to be addressed, as biotreatment is not yet considered acceptable for treating drinking water in this country.

Adsorption

Adsorption is another means for removing ClO_4^- from solution by collecting it on a suitable adsorbent. Various adsorbents have been tested, and ion exchange (IE) resins were identified as being capable of removing ClO_4^- from groundwater (Foster Wheeler, 1998 [see Appendix B-2 below]; Venkatesh et al., 1999; Clifford, et al., 1999), and have been tested in a pilot study at the JPL site (see Appendix C of this report). Results from JPL studies and others indicate that IE is capable of efficiently removing ClO_4^- from groundwater. This technique has advantages in being amenable to flow-through systems, and in minimizing the need for addition of chemicals. Furthermore, ion exchange can be used to produce very clean effluent streams, and the technology is amenable to pump and treat systems.

The major disadvantage of IE is that while the ClO_4^- is immobilized on the IE resin (adsorbent), it is not destroyed. When the resin is saturated with ClO_4^- , it is regenerated by flushing it with a 5-10% sodium chloride (NaCl) solution (brine), which removes the ClO_4^- by replacing it with Cl^- .

ions. This brine, which contains ClO_4^- at much higher concentrations than the original groundwater influent must then be treated or disposed of appropriately.

Two approaches for destroying ClO_4^- in the brine have been identified and are currently being investigated: biological destruction (through biological reduction as described above), and catalytic destruction. It was initially hoped that biological destruction would be capable of destroying ClO_4^- in the brine, and although research is still active in this area, this process has not yet been satisfactorily demonstrated for a ClO_4^- IE application. This is likely due to the fact that 5-10% sodium chloride brine must be used to regenerate the resins, and efficient bacterial reduction of ClO_4^- in this restrictive environment has not yet been reported.

The catalytic destruction system is a proprietary system designed by Calgon Carbon Corporation, which involves a catalytic reactor system for destroying ClO_4^- [as well as nitrate (NO_3^-)], followed by a nanofiltration system for removing sulfate (SO_4^{2-}) (refer to Appendix C of the FS report). This system serves to purify the brine waste from the IE, which can then be re-used in regeneration, greatly reducing the volume of waste.

Membrane Separation

Several pressure-, or gradient-driven membrane separation techniques are now widely applied to treat drinking and waste waters. The technique best suited to removing anionic solutes such as ClO_4^- is reverse osmosis (RO). As with IE, RO can be used to produce very clean effluent streams at the required flow rates. Modern RO technology has advanced significantly in recent years, and appears to be as potentially feasible as IE. The space requirements are comparable to IE, and the process is similarly predictable. A potential advantage of RO compared with IE is that while IE will remove only anionic compounds, RO is capable of removing a wide variety of compounds. Preliminary bench-scale studies were conducted to test RO for treating JPL groundwater. RO was capable of removing ClO_4^- from groundwater to levels approaching non-detect, and that with scale-up and further refinement of the process, non-detectable ClO_4^- levels appear to be achievable (refer to Appendix D).

As with IE, ClO_4^- is not destroyed during the RO process, rather it is concentrated and collected in a "rejectate", which is produced in greater volume than the IE brine (for a given flow rate), but is less saline. Studies were conducted on behalf of JPL to evaluate biotreatment of RO rejectate using four bioreactor configurations: the PBR and FBR mentioned above, and in addition, a matrix biological film reactor (MBFR), and a continuous stirred tank reactor (CSTR). These studies have indicated that ClO_4^- in the RO rejectate can be reduced to non-detect levels (see Appendices D, E and F).

Combinations of Techniques

Because discharge requirements for treated water are very stringent, the most likely scenario is one in which a combination of the above mentioned techniques will provide the most effective

system. A pilot study is currently being planned at JPL, which will potentially test IE, RO, biotreatment, and catalytic destruction in various combinations to determine an optimal configuration for a full-scale treatment system. Results of the pilot study are expected to be used to design and construct a full-scale ClO_4^- -treatment plant capable of achieving non-detect levels on a consistent basis.

5.0 SUMMARY

Perchlorate has only recently been identified as an environmental contaminant, and information regarding its behavior in soil/water systems as well as remediation techniques to remove it from groundwater is limited. Perchlorate consists of the anionic component of a salt, and is very soluble and stable at temperatures typically observed in groundwater systems. In light of these characteristics, ClO_4^- is considered to be persistent and mobile in groundwater, which is supported by the fact that it is present off-site in groundwater directly downgradient from JPL, long after discharges are believed to have occurred.

In terms of its toxicology, ClO_4^- appears to inhibit iodine uptake by the thyroid gland, but past studies are considered inadequate to develop reliable regulatory levels. Consequently, a conservative interim action level of 18 $\mu\text{g/L}$ has been established, and results of comprehensive toxicological studies are currently being evaluated. These studies are expected to culminate in establishment of new regulatory levels sometime in the near future.

Because of its non-volatile nature, ClO_4^- is not subject to treatment techniques currently used to remove VOCs from groundwater. Remediation techniques for treating ClO_4^- -impacted groundwater are currently under development, and research efforts of JPL and others have identified three potentially applicable options. Biological reduction is advantageous in that it brings about destruction of ClO_4^- . Drawbacks of biotreatment potentially include the size of the reactors needed for high flow rate applications, and public perception problems with the ultimate disposition of biotreated water. Ion exchange and reverse osmosis are also applicable techniques for treating ClO_4^- -impacted water. A disadvantage of these techniques is that ClO_4^- is not destroyed, and a concentrated waste stream is generated, which necessitates a secondary treatment to destroy the ClO_4^- . In light of what is presently known, a combination of techniques will most likely be needed to provide a solution that is both technically and economically feasible.

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